USNRDL-TR-701
16 December 1963

REQUIREMENTS FOR MILITARY RADIACS
2. EFFECT OF THE OPERATOR ON THE ENERGY-DIRECTIONAL RESPONSE OF PORTABLE RADIATION INSTRUMENTS

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ADMINISTRATIVE INFORMATION

This report covers a portion of the work authorized by the Bureau of Ships, Subproject SF 011 05 04, Task 6191. Details are found in the U.S. Naval Radiological Defense Laboratory's Technical Program Summary for Fiscal Years 1964-1966 of 1 October 1963 under Program B-5, Problem 1, entitled "Radiac Analysis." This study was supported through funds provided by the Bureau of Ships on Budget Project 21, Allotment 178/64.

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12ND NRDL P1 (9/63)

ABSTRACT

This report presents the results of experiments designed to determine the response of selected military high-range radiacs to extended gamma radiation fields with and without a phantom (simulated operator). The IM-125/PDR-43, IM-153/PD, IM-108A/PD, PDR-63 (USNRDL prototype), and DT-60(XN-2)/PD were tested with point sources of radiation with energies of 70, 120, 180 keV (eff), 667 keV (Cs^{137}), and 1170, 1330 keV (Co^{60}) at radiation intensities in the range 1 to 5 r/hr. Assuming that response of these radiacs to extended-field radiation sources can be inferred from their response to multilateral point sources at specific angles of elevation and over 360 deg of arc, it has been found that response to radiation back-scattered from the operator compensates for decrease in response due to body (operator's) attenuation to an extent determined by type of radiac, carrying mode, and radiation energy. The presence of the operator has little effect on the response of the IM-125/PDR-43. Extended-field response of the IM-153/PD, IM-108A/PD, PDR-63, and DT-60(XN-2)/PD are all substantially decreased by the presence of the operator in varying degree, dependent on radiac type and radiation energy. Using present calibration methods, the net effect of the operator is to cause all of the radiacs tested, except the DT-60(XN-2)/PD, to indicate about 0.75 of the true free-field radiation dose rate or dose. When worn by an operator, the DT-60(XN-2)/PD indicates about 0.65 of the free-field dose. These results are probably typical of portable radiation detection instrument response to extended fission product fields when held by an operator.

SUMMARY

The Problem

How does the presence of an operator affect the response of present military high-range gamma radiacs to extended-field sources of radiation?

The Findings

For the radiation source configuration specified, this paper presents experimental results that show: (1) without an operator, present military radiacs indicate less than the true free-field doses or dose rates when calibrated by methods currently in use; (2) with an operator, the IM-125/PDR-43, IM-153/PD, IM-108A/PD, and PDR-63 radiacs indicate about 0.75 of the true free-field dose or dose rate values; and (3) the DT-60(XN-2)/PD phosphate glass dosimeter indicates about 0.65 of the true free-field dose.

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1. INTRODUCTION

Present high-range military gamma radiation radiacs are customarily calibrated on point-source Co^{60} and Cs^{137} radiation ranges. Calibration is accomplished by: (1) orienting the radiac relative to the source in a specified manner so that the sensitive volume of the detector is not shielded by dense components such as batteries and meters; (2) adjusting the radiac to indicate doses or dose rates equal to those indicated by an air-equivalent ion chamber. While this calibration method may produce radiac indications which are accurate for one energy point-source exposure when the radiac is properly oriented, it does not account for radiation absorption by dense components from directions other than that used in calibration. Further, this calibration method does not take into account that the operator's body absorbs energy from radiation passing through him and, in addition, becomes a source of back-scattered photons by direct radiation.

Absorption and back-scatter coefficients are both energy dependent; so radiac response is also influenced by the spectral distribution of photon energies in the radiation field. The result of this situation is that, in extended radiation fields, radiation response with an operator present is simultaneously reduced by absorption and increased by back-scatter. A number of experiments[1,2,3,4] have been conducted under realistic field conditions to determine the gross response of "properly" calibrated radiac devices to extended fission product fields both with and without an operator. These tests have clearly demonstrated the failure of existing devices to properly indicate exposure dose rate in either circumstance (with or without operator). Unfortunately, however, these experiments did not provide the detailed data necessary to permit the definition of improved calibration procedures or to provide guidance for the radiac developer.

The study reported here was undertaken to provide such information. While the results obtained should be immediately useful in defining

better calibration procedures for existing radiacs and in giving the developer a better understanding of radiac performance in extended fields, it is recognized that these results furnish only part of the required information. To develop radiac response specifications that are meaningful for military operations requires understanding of the entire system; e.g., source-operator-biological effects-data utilization. This study is a part of the system outlined; however, the other parts must be completed before proper perspective can be obtained.

1.1 Objective

The objective of this investigation was to determine how and to what extent the response of military radiacs to gamma radiation as a function of energy and orientation is modified by the presence of an operator.

2. APPROACH

It is impractical to expect to duplicate in the laboratory all of the variations in source distribution, size of operator, amount of equipment carried by him, his position relative to the radiac, etc. It is possible, however, to obtain from experimental arrangements the basic data from which the probable results of measurements made in particular field situations can be inferred.

The approach adopted for this investigation was as follows:

a. Assume that the Masonite man-phantom designed and fabricated at the Naval Medical Research Institute, Bethesda, Maryland, for depth-dose determinations has the approximate gamma-scattering and gamma-attenuation characteristics of a lightly clothed man of comparable size who carries no extra equipment.*

b. Establish a gamma radiation range with a beam cross-section sufficiently large to guarantee irradiation of the whole phantom, yet not so large as to produce unwanted scattering from walls and equipment. (The minimum beam diameter was 1.5 m at 4 m distance from the source.)

*Measurements made later with live operator substantiate this assumption. (See paragraph 5.1.2.)

c. Assume that the effect of the operator on different radiacs will vary because of differences in their energy-directional response characteristics. A variety of radiacs should then be examined.

d. Select: (1) radiacs that will be in use by the Armed Forces of the United States for the next few years, including advanced developmental models, and (2) positions of each radiac (relative to the phantom) that are probable measuring positions in operational use. (In this regard, it should be recognized that a frequent, perhaps the most frequent, use of a radiac is as an exploratory tool to determine whether or not a radiation hazard is present. When used in exploratory surveys, it will probably be carried in any comfortable position where it can be observed periodically to see whether or not it is indicating. High accuracy is not important in these instances; therefore, an increased response due to gamma-scattering from the operator would not be objectionable. It is important, though, that a significant hazard not be missed; thus, the principal concern in an exploratory survey is with attenuation of the gamma flux by the operator. When the situation requires accurate measurements, the position of the radiac will be changed, if necessary, so that it can be held steady for careful observation of the indication, manipulation of the controls, and so on. It is in this operational situation that errors due to scattering from the operator may be important, in addition to those due to attenuation by his body.)

e. Determine for each radiac how the presence of an operator (the phantom) modifies the response of the radiacs to selected energies and directions of gamma radiation.

f. Verify that radiac response to an isotropic radiation field can be inferred from the response to a series of point-source unilateral exposures.

3. PROCEDURE

3.1 Radiacs Used in Tests

Tests were conducted on the following radiac devices:

a. Radiacmeter IM-125/PDR-43, Standard Military High Range Beta-Gamma Radiac; ratemeter;

b. Radiacmeter IM-153(XN-1)/PD, Electronic Recycling Alarm Dosimeter, Applications Engineering Model;

c. Radiacmeter IM-108A/PD, Standard Military High Range Gamma Radiac; ratemeter;

d. PDR-63, Wide Range Beta-Gamma Radiac, Advanced USNRDL Developmental Model; ratemeter;

e. DT-60(XN-2)/PD, Military Phosphate Glass High Range Dosimeter. (The DT-60(XN-2)/PD is a developmental dosimeter.[5] Its design was based on the experimental results of Operation REDWING tests[3] with the DT-60/PD. The present DT-60B/PD and DT-60C/PD dosimeters are production devices based on the DT-60(XN-2)/PD.)

Brief descriptions of these radiacs appear in the Appendix.

3.2 Positioning of Radiac in Radiation Beam

3.2.1 Without Operator (Phantom)

All radiacs except the DT-60's were suspended in a wide-mesh sack so that, referenced to the laboratory floor, the suspension method provided vertical and horizontal axes of rotation through the radiac detector of 360 and 180 deg, respectively. Measurements of radiac response around the vertical axis (azimuth) were made at angular displacement increments of 45 deg and at angles referenced to the horizontal (elevation) of 45 deg above, 0 deg, and 45 deg below. Zero reference for both azimuth and elevation was the position that the radiac would have been in if an operator had been holding it in normal manner facing the radiation source.

The DT-60 dosimeters were attached to a thin fiberboard shell of the same dimensions as the phantom to facilitate positioning and to standardize doses. Aside from the difference in suspension and mounting, the experimental technique used in positioning the DT-60 dosimeters was the same as that of the other radiacs.

3.2.2 With Operator (Phantom)

The positioning of the radiac with an operator was such that, in respect to the radiation source, the radiac position for each part of

the test was the same as without an operator; i.e., the operator was a modifier of the radiac's environment. The positioning of the radiac on the operator is described in paragraph 3.3. Figures 1a and 1b show the operator, radiac, and source relationship.

3.3 Radiac Positions on the Operator

The probable field measuring position for each radiac was determined by observing a number of people with field experience as they made simulated measurements.

The IM-125/PDR-43 is carried by its handle at arm's length or is slung over a shoulder at about belt height. Measurements are generally made with the radiac by holding it in front of the body parallel with the ground at about belt height, with the back of the radiac held against the body for stability (Fig. 1b and 2a).

The IM-153/PD was designed as a belt-carried radiac and is most conveniently used that way. The accumulated dose is easily seen by glancing at the register for any front-body belt position of the radiac (Fig. 2b).

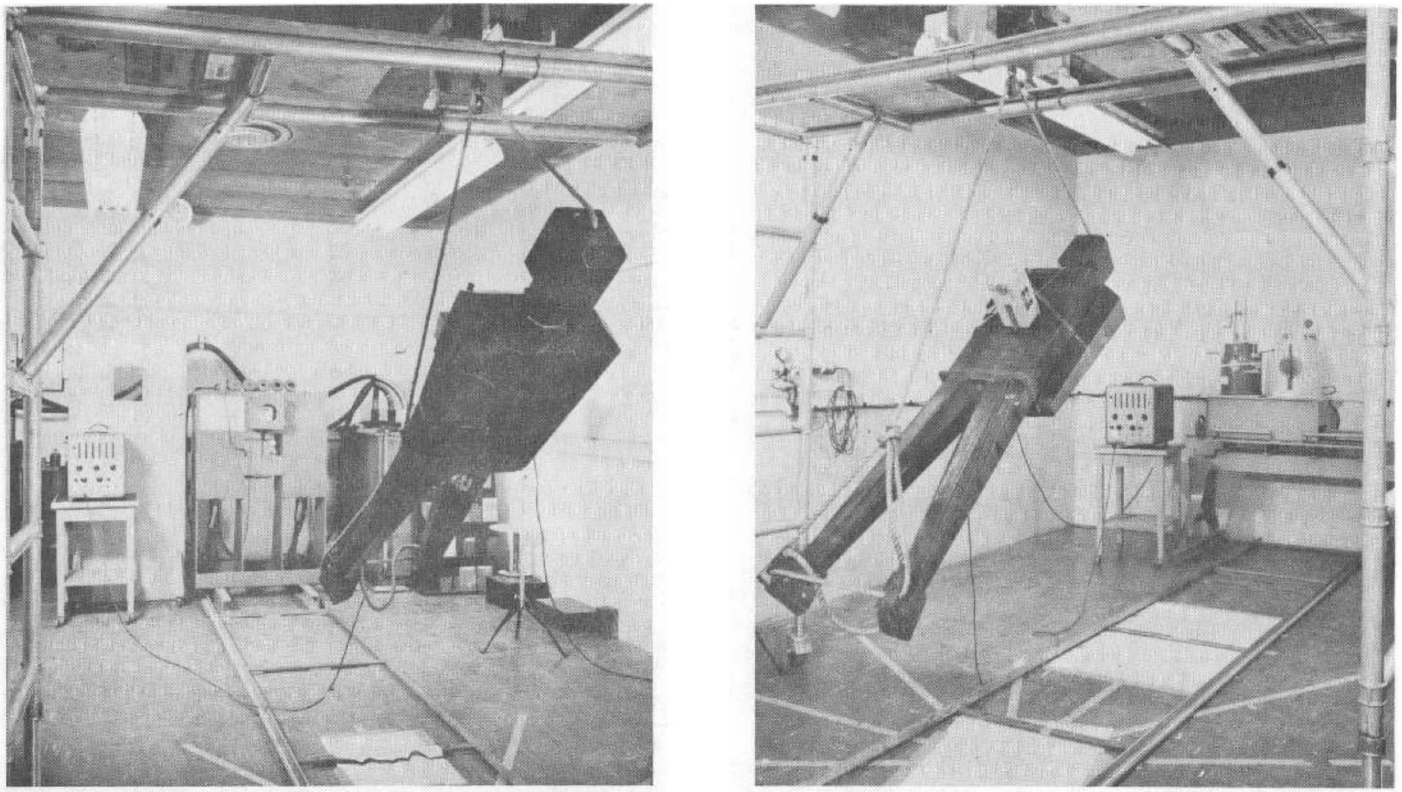
The IM-108A/PD is a belt-carried radiac. Its "L" shape makes a front rather than side position preferable, so that the projecting meter housing does not interfere with arm movements. Any belt position within about 45 deg of body center is satisfactory for performing measurements (Fig 3a). (It is recognized that a side-carry position is preferable for a man lying prone or crawling about, but it is considered unlikely that a majority of meter readings will be made under these conditions.)

The PDR-63 is intended to be carried in the same manner as the IM-108A/PD (Fig. 3b).

The DT-60(XN-2)/PD is suspended by a neck-cord or chain at upper chest height.

The test positions chosen for this investigation were based on the usage positions outlined above.

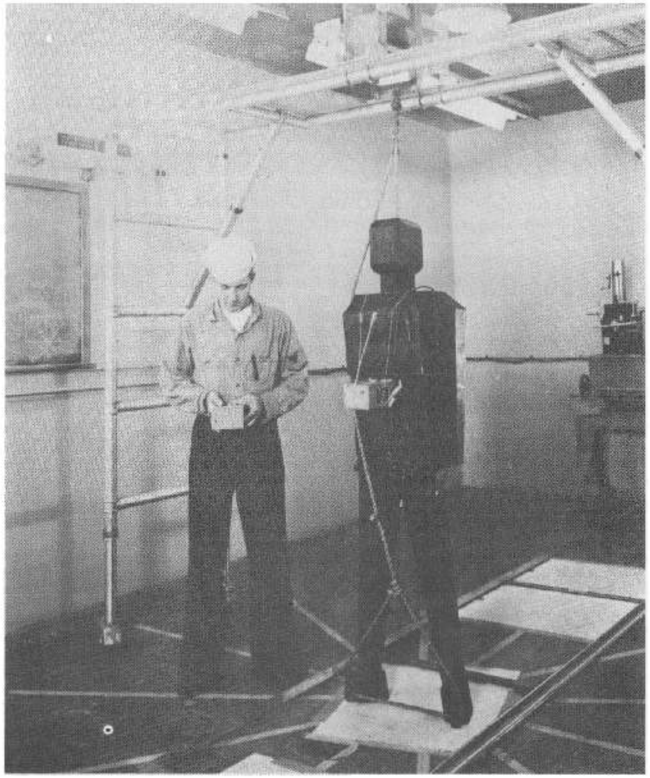
All ratemeters and the IM-153/PD Alarm Dosimeter were centered in front of the operator at belt height. This required no change in position for the IM-125/PDR-43 and only small displacements for the other radiacs. The positioning of the phantom in the beam was considerably simplified by having similar locations for all radiacs used. The



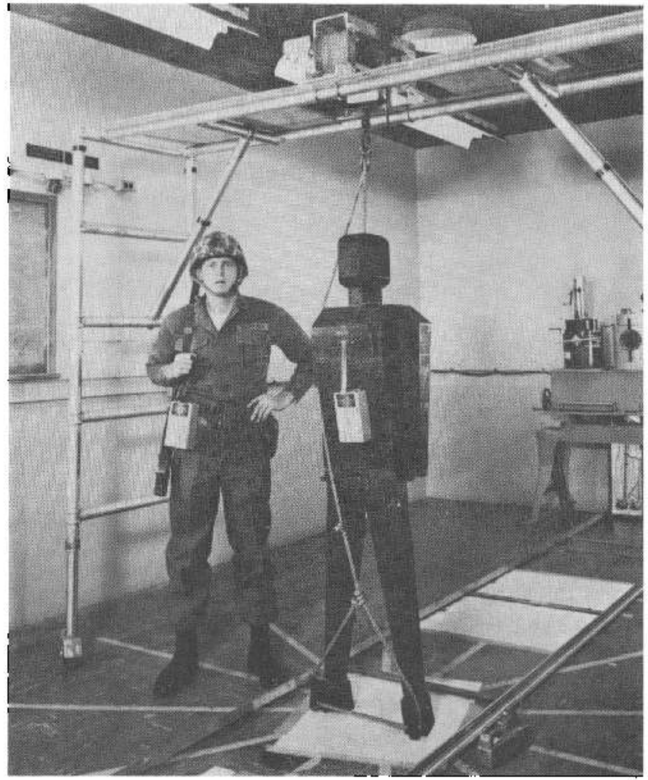
(a) X-ray Generator

(b) Co^{60} and Cs^{137} Sources

Fig. 1 Radiation Range, Phantom and Scaffold

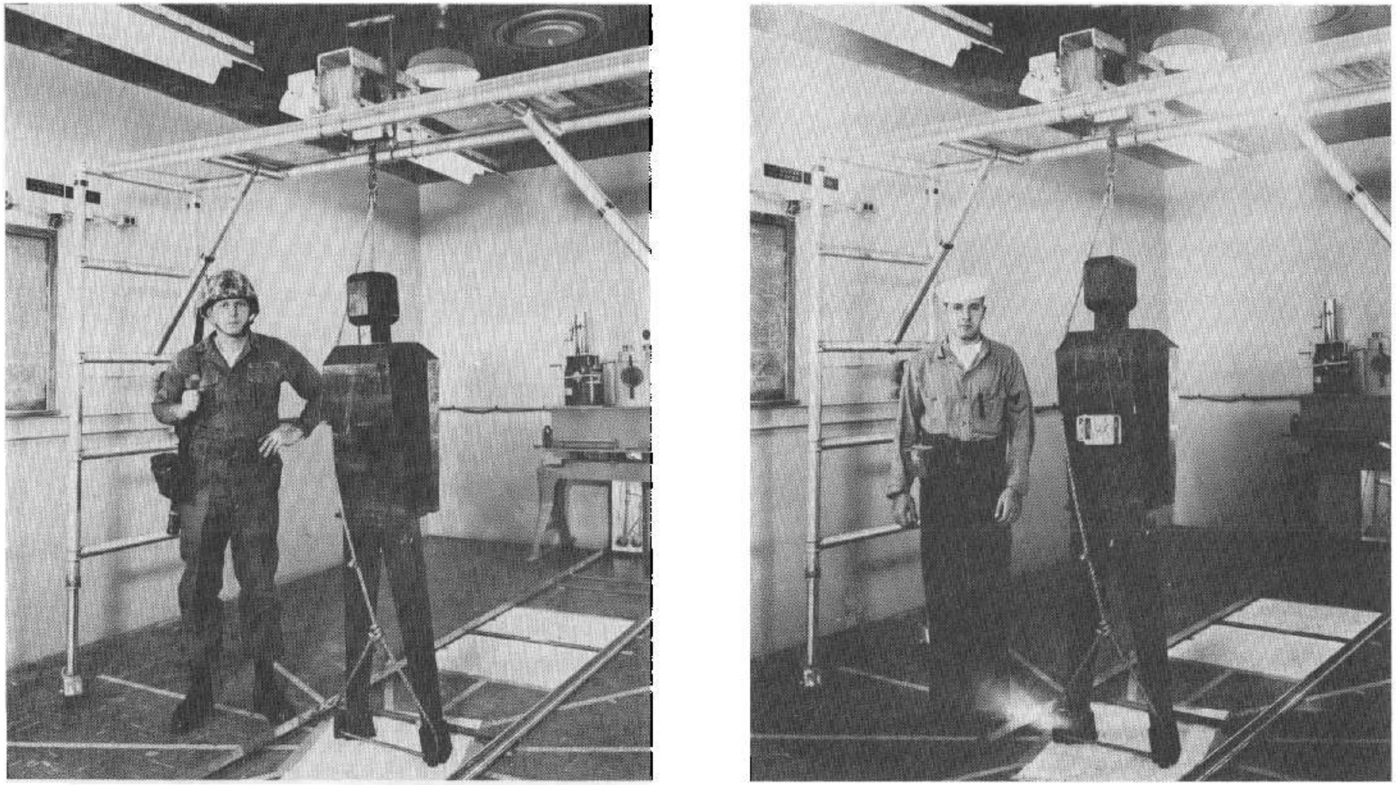


(a) Radiacmeter IM-125/PDR-43



(b) Radiacmeter IM-153/PD

Fig. 2 IM-125/PD and IM-153/PD Positions for Field Use by Operator and for Testing on Phantom



(a) IM-108A/PD Radiacmeter

(b) PDR-63 Radiacmeter

Fig. 3 IM-108A/PD and PDR-63 Positions for Field Use by Operator and for Testing on Phantom

DT-60(XN-2)/PD dosimeters were placed on the phantom in the approximate positions they would ordinarily occupy. (The front and back of the phantom were considered equivalent positions for dosimeters insofar as modification of the radiation field by the operator was concerned. By using both the front and back, simultaneous exposures of two dosimeters could be made while maintaining adequate separation to minimize the effects of scattering from one to the other.)

3.4 Methods of Measuring Radiac Response

Prior to the experimental tests, each radiac was calibrated on a Co^{60} range with the same source-radiac geometries recommended in the individual radiac instruction manuals. All methods place the radiac in a position relative to the source so that the detector is not shielded by the batteries, meter, or other dense parts. Suitable calibration curves of response (pulse rate, pulse period, or meter voltage drop) as a function of dose rate for the specific measurement method planned for each device were then obtained. The measurement methods used for each radiac are set forth in the following paragraphs.

3.4.1 IM-125/PDR-43

GM (Geiger-Mueller) tube pulses were scaled with a scaler-electronic clock combination for each test position. The response in roentgens per hour was then determined from calibration curves displaying dose rate as a function of average pulse rate.

3.4.2 IM-108A/PD

The radiac was calibrated and operated under test with the "check" switch closed at all times. The check switch changes the normal 500 r/hr (roentgens per hour) compressed full-scale sensitivity to a full-scale sensitivity of 10 r/hr. The voltage drop across the meter movement resulting from radiation exposure was fed into a stable VTVM (vacuum tube voltmeter) whose amplified recorder-drive output was a linear function of input voltage. The VTVM output was measured and recorded directly by a digital voltmeter-printer combination. Dose rate information was determined from calibration curves of meter voltage as a function of dose rate.

3.4.3 IM-153/PD and PDR-63

These instruments incorporate ionization chamber circuitry which loses charge when irradiated and then recharges after a fixed increment of dose has been accumulated. The frequency of the discharge-charge

cycle is proportional to the radiation rate. The linearity of period (time between recycling pulses) with respect to radiation rate in roentgens per hour was established and, thereafter, period measurements were used with these instruments. Time between pulses was measured with a frequency counter and printer combination. Dose rate information was obtained from calibration curves of period as a function of dose rate.

3.4.4 DT-60(XN-2)/PD Dosimeters

The DT-60 glass dosimeters were read on the M-Pool Standard Reader, located at USNRDL, prior to any exposures and after all exposures were concluded. (The M-Standards are phosphate glass dosimeter standards which, with a specially designed, highly stable reader constitute the primary DT-60 standard calibration system.) The standard reader can give the exposure dose indicated by a DT-60 with an accuracy of ±1 r if considerable care is taken to control instrument drift, maintain constant temperature, etc. Because of the large number of low level exposures made, it was not considered feasible to read each exposure dose separately. Instead, a complete exposure record was kept for each dosimeter for comparison with the post-dose standard reader results.

3.4.5 Accuracy and Reproducibility of Radiation Range Dose Rates

The calibration of the various radiation ranges in dose rate as a function of source distance was made with a transfer ion chamber standard manufactured and calibrated by NBS (National Bureau of Standards). The transfer standard is used in conjunction with a vibrating reed electrometer* in the manner described by Day and Attix.[6] Both the transfer standard and the electrometer input resistors are periodically calibrated by NBS. Determinations of radiation dose rates made with this system are reproducible within ±2 percent of mean reference values for the dose rates used.

3.4.6 Repeatability of Measurements

Throughout the series of measurements a continuing effort was made to guarantee that instrument errors were held to a minimum. At the beginning and end of each series of measurements and periodically during the series, the response of the test radiac was checked in a standard configuration. The following description of the IM-125/PDR-43 procedure illustrates the methods employed.

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*Cary Model 31, manufactured by Applied Physics Corp., Monrovia, Calif.

Pulses appearing across the GM tube current-limiting resistor as a result of radiation exposure were counted with a combination scaler-electronic clock. Pulses resultant from each exposure rate of 60 mr/hr or greater were counted to a minimum of 10,000 counts, with most exposure rates less than 60 mr/hr counted to 1,000 counts because of time considerations. Indicated dose rate was then determined from a calibration curve of dose rate as a function of time required to count 1,000 or 10,000 pulses. This curve had been prepared from data obtained with Co^{60} and covered the range from 20 mr/hr to 5.0 r/hr. The response of the radiac to its internal check source at time of initial calibration was used as a reference base for all subsequent test work. Check source response was recorded prior to, during, and after each experimental run and was reproducible within ± 1.5 percent of the original reference value.

3.4.7 Scatter, Attenuation, and Live Operator Measurements

During the course of the experimental work it was recognized that the analysis of the radiac response data with phantom would be simplified if phantom back-scatter, forward-scatter (build-up), and attenuation data were obtained. Accordingly, experiments were designed to supply this information. The experiments and results are described in section 5.

To demonstrate that the particular phantom used in the experimental work was equivalent to a man of the same size, a limited number of radiac exposures with a live operator (author) were made. Test results are given in paragraph 5.1.2.

3.4.8 Source-Radiac Geometry Considerations

Since in the ideal case an extended fallout field can be considered to be an infinitely large number of individual sources distributed over a plane, the response of a radiac suspended over such a plane is the sum of the individual contributions at the radiac from each source. A similar statement can be made for an isotropic field. Consequently, a laboratory procedure using a radiac positioned at various angles of azimuth and elevation relative to a radiation source will result in a series of data points that can be used to infer the response of the radiac to an isotropic or extended field source. Such a procedure can be as detailed as desired. With an operator, however. scattering from the phantom may conceivably be enough different in the two cases, e.g., field and laboratory, to cause significant error in the results because of differences in the depth dose distribution in the two cases. Fortunately, Bond, et al,[7] have shown that the

Co^{60} depth dose distribution produced in a large animal phantom by using bilateral, ring source, or crossfire techniques is essentially the same as that produced by an extended fallout field. (Crossfire exposure is obtained by simultaneously irradiating the phantom with two opposed radiation sources.) In section 4, the experimental results of measurements made with point-sources of radiation at fixed increments of arc referenced to the radiacs have been averaged over 360 deg, simulating a ring source exposure. Consequently, it can be inferred that significant error will not be introduced by collecting the radiac response data using a point source and extrapolating to the extended-field or isotropic situation.

One additional point needs clarification here. Certainly the scattered radiation incident at the radiac or phantom is radically different for a source close by as compared with one a few mean free paths away. This does not, however, influence the results since the data obtained are not dependent on the origin of the incident photons.

To illustrate the identity between crossfire exposure and additive single source exposures, a simple experiment using two Cs^{137} sources at 0 and 180 deg azimuth irradiating an IM-125/PDR-43 was performed. Exposure data were obtained with the instrumentation described in paragraph 3.4.1. Measurement results are given in Table 1.

TABLE 1

Response of IM-125/PDR-43
to Cs^{137} Crossfire Irradiation

Condition	Response Source 1 (r/hr)	Response Source 2 (r/hr)	Response 1+2(r/hr)	Crossfire Response (r/hr)
No Phantom	1.48	0.72	2.20	2.26
With Phantom	1.49	0.21	1.70	1.83

3.4.9 Radiation Sources

Co^{60}, Cs^{137}, and X-radiation sources were used in the experiments.

The Co^{60} and Cs^{137} were essentially point-sources housed in lead "pigs". Dose rates used with these sources were in the range 2 to 5 r/hr at distances from 2 to 4 meters.

The X-ray beams were generated by a Westinghouse 250 KV Constant Potential X-Ray machine. This machine has shutter, collimator, input power regulation, and other modification features which make it especially suitable for radiac work.[8] X-ray beam spectra are shown graphically in Fig. 4.

The X-ray spectrum band width is a compromise among three factors: minimum practical distance from X-ray tube focal spot to radiac, minimum acceptable dose rate, and maximum sharpness of the X-ray spectrum at half-energy points. Based on these parameters the following combinations were used:

X-ray Tube Voltage (KV)	Added Filtration (mm)	Effective Energy (KV)
250	15.00 Cu 6.34 Al	180
150	3.96 Cu 6.34 Al	120
90	1.00 Cu	70
50	0.13 Cu	35

The energy distributions shown in Fig. 4 were determined by calculation and confirmed by pulse height analysis measurements made with a crystal spectrometer. The method of calculation is that described by Ehrlich and Fitch,[9] based on Kramers' theoretical formula.[10] (Kramers' formula assumes that a linear plot of intensity-vs-energy of photons emitted from an X-ray tube target is a straight line with constant slope, -C, as expressed by

$$I(E)dE = -C(E-E_o)dE,$$

and that the spectral intensity distribution in the photon-energy interval dE is $I_o(E)dE$.)

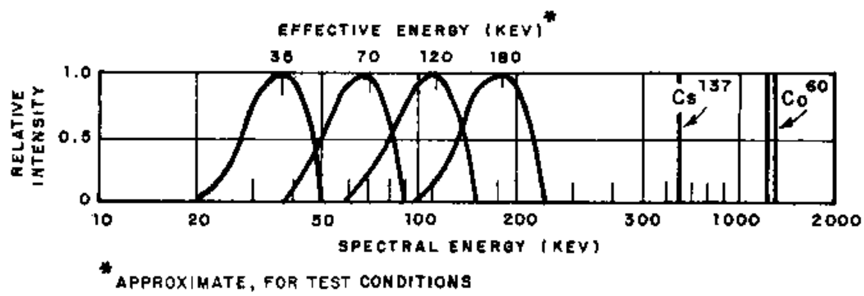


Fig. 4 Energy Distribution of X-ray Beams

4. EXPERIMENTAL RESULTS OF THE EFFECT OF THE OPERATOR ON RADIAC RESPONSE TO POINT SOURCE RADIATION

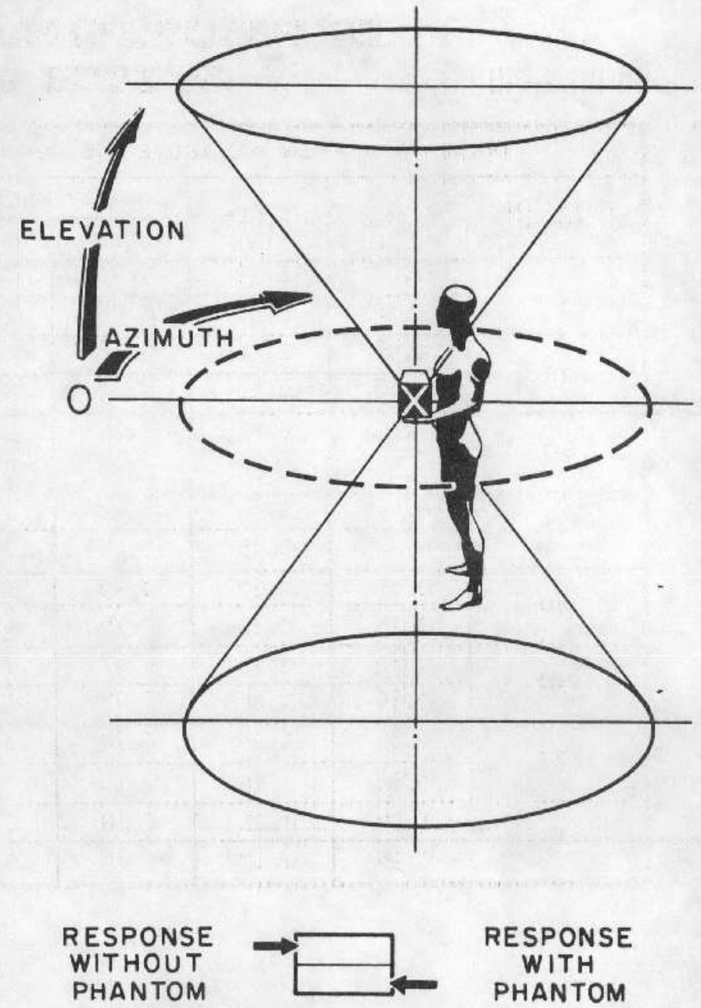
The results of measurements to determine the response of the radiacs with and without an operator to radiation as a function of radiation energy and direction are tabulated in Tables 2 through 5. Figures 5 through 8 are polar plots of the same data.

The results of measurements with the DT-60(XN-2)/PD dosimeters are given in Table 6. Two dosimeters were exposed with the phantom and two without the phantom.

TABLE 2

IM-125/PDR-43

DIRECTIONAL & SPECTRAL SENSITIVITY OF RADIAC WITH & WITHOUT SIMULATED OPERATOR



VALUES GIVEN ARE RELATIVE TO RESPONSE OF RADIAC ALONE TO Co^{60} RADIATION IN DIRECTION OF ZERO AZIMUTH AND ZERO ELEVATION.

	IRRADIATION FROM 45° ABOVE THE HORIZONTAL					IRRADIATION IN THE HORIZONTAL PLANE					IRRADIATION FROM 45° BELOW THE HORIZONTAL				
AZIMUTH (DEG)	Co^{60}	Cs^{137}	X-RAY ENERGY (KEV EFF)			Co^{60}	Cs^{137}	X-RAY ENERGY (KEV EFF)			Co^{60}	Cs^{137}	X-RAY ENERGY (KEV EFF)		
			180	120	70			180	120	70			180	120	70
0	1.00	1.29	0.95	1.06	0.71	1.00	1.25	0.92	1.11	0.74	0.92	1.17	0.86	1.21	0.88
	0.92	1.14	0.84	1.01	0.68	0.99	1.23	0.91	1.15	0.78	0.94	1.24	0.92	1.24	0.91
45	0.98	1.21	0.89	0.89	0.54	0.99	1.24	0.92	1.02	0.65	0.94	1.15	0.85	1.02	0.64
	0.94	1.12	0.83	0.89	0.54	1.01	1.25	0.93	1.07	0.62	0.94	0.99	0.73	1.04	0.62
90	0.72	0.76	0.56	0.29	0.11	0.84	0.98	0.73	0.52	0.24	0.86	1.03	0.76	0.71	0.26
	0.78	0.85	0.63	0.43	0.20	0.83	0.96	0.71	0.50	0.22	0.88	1.05	0.78	0.90	0.33
135	0.76	0.84	0.62	0.37	0.13	0.86	1.04	0.77	0.63	0.34	0.75	0.99	0.73	0.55	0.21
	0.80	0.75	0.55	0.42	0.16	0.92	1.09	0.81	0.72	0.36	0.91	1.11	0.82	0.56	0.21
180	0.71	0.67	0.49	0.66	0.45	0.48	0.37	0.28	0.06	0.00	0.76	0.88	0.65	0.57	0.17
	0.26	0.20	0.15	0.06	0.0C	0.22	0.19	0.14	0.06	0.00	0.40	0.37	0.27	0.10	0.00
225	0.80	0.91	0.67	0.48	0.26	0.88	1.05	0.78	0.67	0.34	0.85	0.94	0.70	0.62	0.22
	0.84	1.04	0.77	0.62	0.33	0.87	1.02	0.76	0.58	0.33	0.94	1.12	0.83	0.65	0.22
270	0.81	0.95	0.70	0.50	0.21	0.91	1.09	0.80	0.76	0.38	0.86	1.02	0.76	0.70	0.15
	0.86	0.96	0.71	0.62	0.31	0.91	1.11	0.82	0.91	0.38	0.89	1.04	0.77	0.82	0.35
315	1.00	1.21	0.90	0.90	0.53	1.00	1.23	0.91	1.00	0.63	0.93	1.12	0.83	1.26	0.60
	0.95	1.17	0.86	0.88	0.50	0.99	1.22	0.90	1.06	0.64	0.96	1.22	0.90	1.08	0.66

INTEGRATED RESPONSE TO VARIOUS DIRECTIONS AND ENERGIES OF IRRADIATION

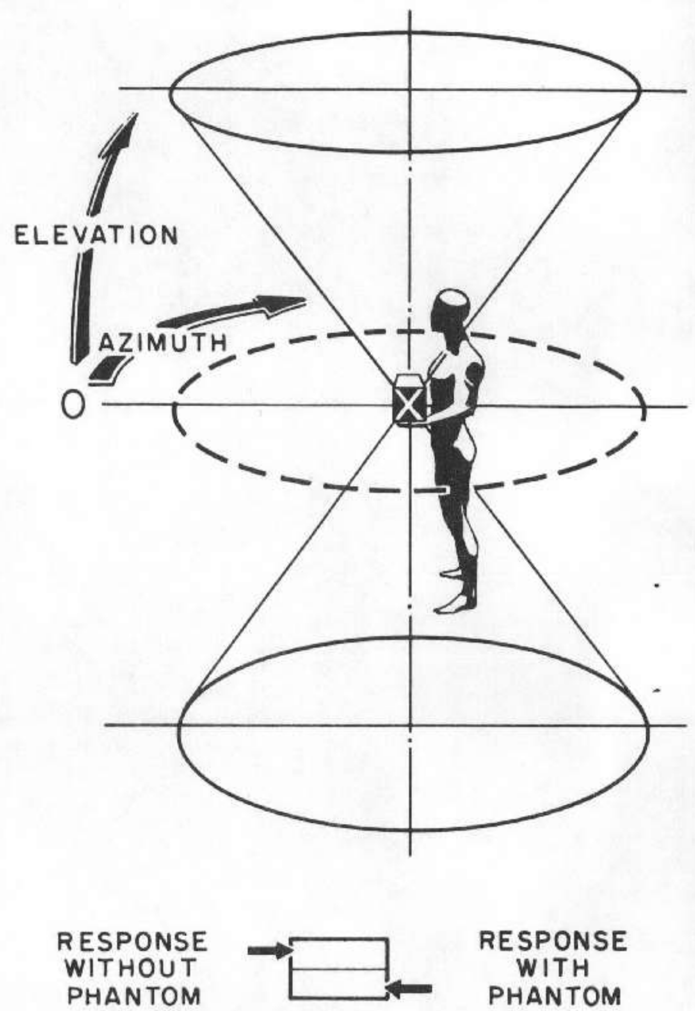
DIRECTION	Co^{60}	Cs^{137}	X-RAY ENERGY (KEV EFF)		
			180	120	70
HORIZONTAL PLANE	0.87	0.76	0.76	0.72	0.42
	0.84	0.75	0.78	0.76	0.42
45° BELOW HORIZONTAL	0.86	0.77	0.81	0.83	0.39
	0.86	0.75	0.80	0.80	0.41
45° ABOVE HORIZONTAL	0.85	0.72	0.67	0.64	0.37
	0.79	0.67	0.66	0.62	0.34

* See Section 4.1.4

TABLE 3

IM - 153/PD

DIRECTIONAL & SPECTRAL SENSITIVITY OF RADIAC WITH & WITHOUT SIMULATED OPERATOR



VALUES GIVEN ARE RELATIVE TO RESPONSE OF RADIAC ALONE TO Co^{60} RADIATION IN DIRECTION OF ZERO AZIMUTH AND ZERO ELEVATION.

	IRRADIATION FROM 45° ABOVE THE HORIZONTAL					IRRADIATION IN THE HORIZONTAL PLANE					IRRADIATION FROM 45° BELOW THE HORIZONTAL				
AZIMUTH (DEG)	Co^{60}	Cs^{137}	X-RAY ENERGY (KEV EFF) 180	120	70	Co^{60}	Cs^{137}	X-RAY ENERGY (KEV EFF) 180	120	70	Co^{60}	Cs^{137}	X-RAY ENERGY (KEV EFF) 180	120	70
0	0.84	0.68	0.79	0.74	0.32	1.00	0.94	1.02	1.09	0.72	0.98	0.97	1.09	1.11	0.73
	0.81	0.78	0.70	0.72	0.24	1.00	1.03	1.16	1.32	0.77	0.99	0.95	1.08	1.36	0.81
45	0.80	0.69	0.74	0.70	0.34	0.96	0.93	0.96	0.94	0.51	0.95	0.84	0.93	0.94	0.52
	0.77	0.78	0.71	0.78	0.32	1.01	0.97	1.07	1.21	0.66	0.97	0.92	1.03	1.23	0.64
90	0.71	0.63	0.53	0.50	0.23	0.80	0.76	0.87	1.08	0.76	0.97	0.89	1.07	1.03	0.65
	0.70	0.64	0.66	0.73	0.37	0.91	0.80	0.86	1.22	0.80	0.98	0.95	0.97	1.10	0.64
135	0.88	0.81	0.83	0.78	0.42	0.95	0.82	0.86	0.90	0.46	0.95	0.76	0.94	0.99	0.55
	0.31	0.22	0.11	0.16	~ 0	0.37	0.26	0.18	0.16	~ 0	0.44	0.38	0.24	0.24	~ 0
180	0.88	0.82	0.86	0.87	0.46	1.00	0.93	1.06	1.09	0.69	0.96	0.79	1.10	1.18	0.82
	0.38	0.30	0.15	0.14	~ 0	0.48	0.36	0.23	0.23	~ 0	0.41	0.36	0.22	0.20	~ 0
225	0.87	0.85	0.78	0.73	0.41	0.95	0.89	0.92	0.87	0.53	0.96	0.81	0.96	0.90	0.52
	0.55	0.32	0.11	0.10	~ 0	0.50	0.27	0.16	0.14	~ 0	0.51	0.41	0.18	0.16	~ 0
270	0.82	0.77	0.64	0.51	0.22	0.93	0.92	0.86	0.84	0.54	0.99	0.90	1.06	1.06	0.64
	0.91	0.81	0.64	0.58	0.26	0.93	0.88	0.85	0.86	0.54	1.02	1.09	0.95	1.04	0.58
315	0.86	0.69	0.81	0.71	0.32	1.00	0.91	1.02	0.94	0.54	0.95	0.92	0.97	0.90	0.52
	0.81	0.88	0.77	0.70	0.33	0.99	0.98	1.09	1.26	0.72	0.99	0.94	0.95	1.08	0.58

INTEGRATED RESPONSE TO VARIOUS DIRECTIONS AND ENERGIES OF IRRADIATION

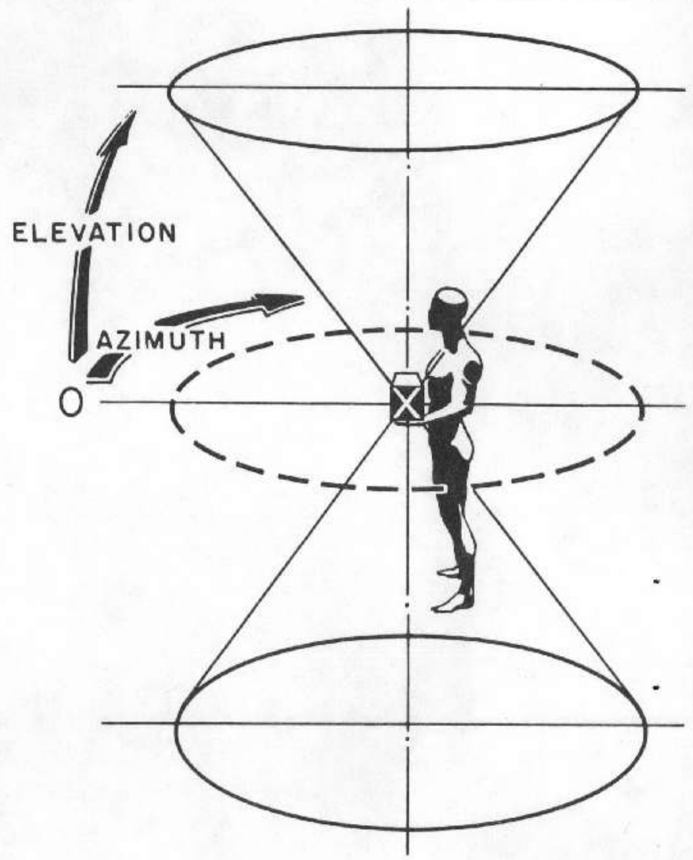
DIRECTION	Co^{60}	Cs^{137}	X-RAY ENERGY (KEV EFF) 180	120	70
HORIZONTAL PLANE	0.95	0.89	0.95	0.97	0.59
	0.77	0.69	0.70	0.80	0.44
45° BELOW HORIZONTAL	0.96	0.86	1.01	1.01	0.62
	0.79	0.74	0.70	0.80	0.41
45° ABOVE HORIZONTAL	0.83	0.74	0.75	0.69	0.34
	0.66	0.59	0.48	0.49	0.19

* See Section 4.1.4

TABLE 4

IM - 108A/PD

DIRECTIONAL & SPECTRAL SENSITIVITY OF RADIAC WITH & WITHOUT SIMULATED OPERATOR



RESPONSE WITHOUT PHANTOM → (upper) / RESPONSE WITH PHANTOM → (lower)

VALUES GIVEN ARE RELATIVE TO RESPONSE OF RADIAC ALONE TO Co^{60} RADIATION IN DIRECTION OF ZERO AZIMUTH AND ZERO ELEVATION.

AZIMUTH (DEG)	IRRADIATION FROM 45° ABOVE THE HORIZONTAL					IRRADIATION IN THE HORIZONTAL PLANE					IRRADIATION FROM 45° BELOW THE HORIZONTAL				
	Co^{60}	Cs^{137}	X-RAY ENERGY (KEV EFF)			Co^{60}	Cs^{137}	X-RAY ENERGY (KEV EFF)			Co^{60}	Cs^{137}	X-RAY ENERGY (KEV EFF)		
			180	120	70			180	120	70			180	120	70
0	0.83	0.87	0.83	0.82	0.68	1.00	1.07	1.04	1.11	0.98	0.95	0.98	1.02	1.11	0.98
	0.86	0.90	0.97	1.00	0.78	1.03	1.07	1.36	1.50	1.40	0.98	0.99	1.11	1.21	1.02
45	0.89	0.94	0.86	0.85	0.70	1.02	1.07	0.95	0.98	0.85	0.97	0.98	0.94	0.99	0.83
	0.97	0.97	1.07	1.09	0.85	1.01	1.09	1.29	1.40	1.22	0.96	1.00	1.19	1.30	1.04
90	0.87	0.93	0.73	0.55	0.56	0.93	0.92	0.96	1.02	0.84	0.89	0.95	0.84	0.95	0.85
	0.96	0.94	0.84	0.76	0.61	0.96	0.96	1.08	1.14	1.15	0.98	0.96	1.06	1.12	0.92
135	0.92	0.96	0.76	0.71	0.57	0.96	0.98	0.84	0.82	0.65	0.90	1.02	0.84	0.85	0.71
	0.55	0.44	0.23	0.24	0.19	0.43	0.32	0.23	0.23	0.15	0.60	0.54	0.29	0.29	0.21
180	0.94	0.94	0.66	0.59	0.42	0.94	0.99	0.87	0.86	0.70	0.90	1.04	1.00	1.03	0.83
	0.41	0.34	0.25	0.24	0.17	0.52	0.41	0.32	0.31	0.22	0.52	0.43	0.24	0.23	0.17
225	0.96	0.95	0.80	0.79	0.62	0.95	1.03	0.86	0.86	0.68	0.89	1.02	0.87	0.87	0.74
	0.44	0.27	0.29	0.27	0.23	0.41	0.32	0.24	0.23	0.17	0.67	0.55	0.54	0.49	0.41
270	0.89	0.96	0.67	0.60	0.48	0.92	0.93	0.98	1.01	0.83	0.91	0.94	0.89	0.97	0.80
	0.91	0.88	0.81	0.73	0.53	0.95	0.97	1.15	1.21	0.95	0.96	0.94	1.09	1.19	0.90
315	0.92	1.01	0.88	0.89	0.73	1.00	1.16	0.98	1.02	0.90	0.97	0.89	0.92	0.95	0.80
	0.96	0.96	1.09	1.11	0.90	1.01	1.05	1.30	1.40	1.17	0.98	0.96	1.20	1.29	1.04

INTEGRATED RESPONSE TO VARIOUS DIRECTIONS AND ENERGIES OF IRRADIATION

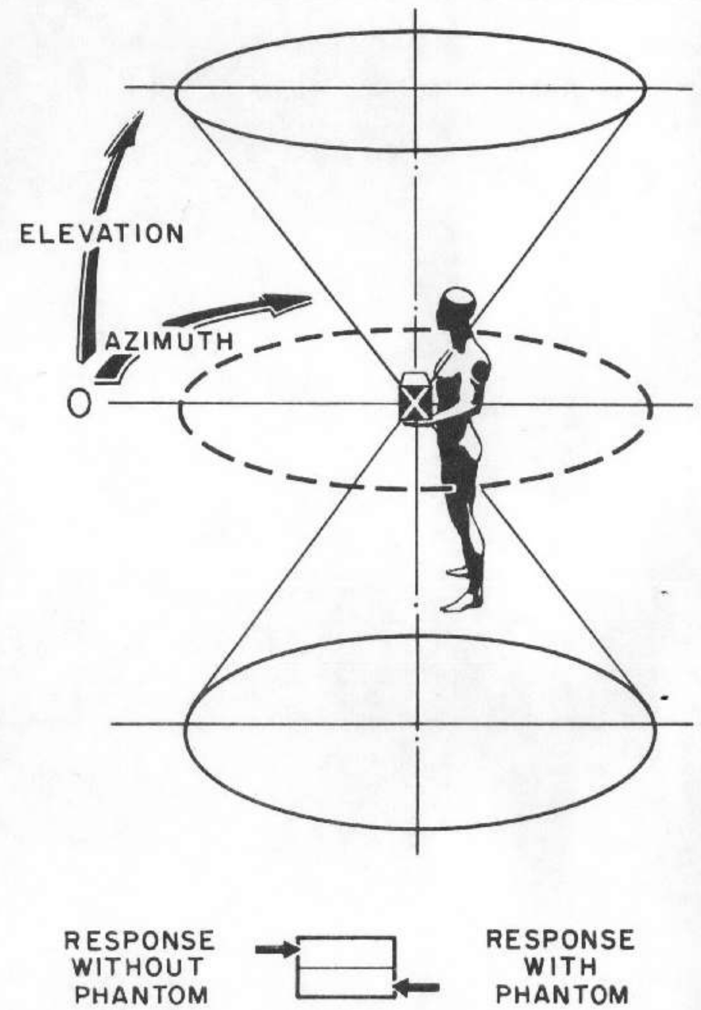
DIRECTION	Co^{60}	Cs^{137}	X-RAY ENERGY (KEV EFF)		
			180	120	70
HORIZONTAL PLANE	0.95	1.02	0.93	0.96	0.81
	0.79	0.77	0.87	0.93	0.81
45° BELOW HORIZONTAL	0.93	0.97	0.86	0.96	0.82
	0.83	0.79	0.84	0.88	0.71
45° ABOVE HORIZONTAL	0.92	0.99	0.77	0.74	0.59
	0.76	0.70	0.69	0.68	0.53

* See Section 4.1.4

TABLE 5

PDR - 63

DIRECTIONAL & SPECTRAL SENSITIVITY OF RADIAC WITH & WITHOUT SIMULATED OPERATOR



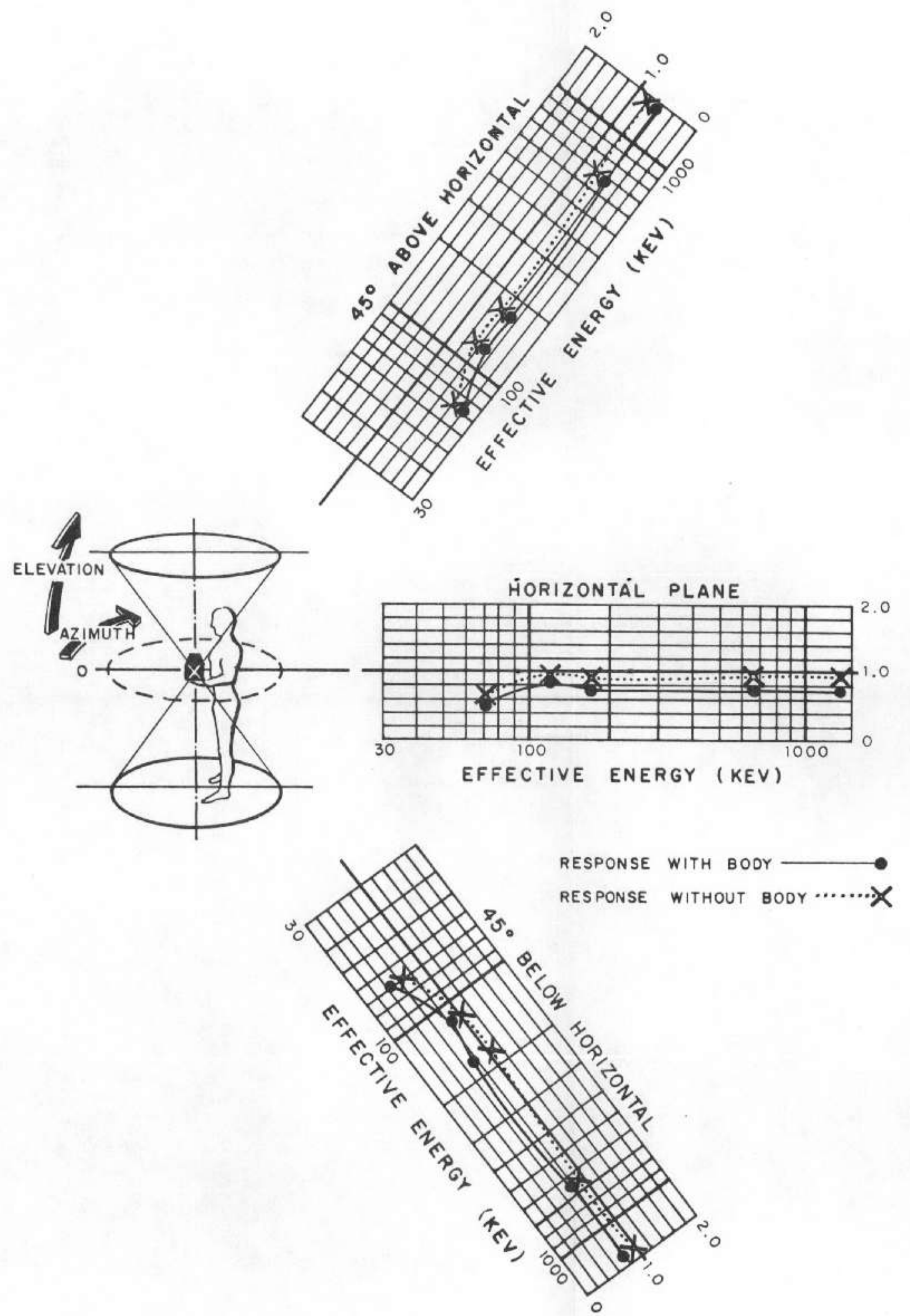
VALUES GIVEN ARE RELATIVE TO RESPONSE OF RADIAC ALONE TO Co^{60} RADIATION IN DIRECTION OF ZERO AZIMUTH AND ZERO ELEVATION.

AZIMUTH (DEG)	IRRADIATION FROM 45° ABOVE THE HORIZONTAL					IRRADIATION IN THE HORIZONTAL PLANE					IRRADIATION FROM 45° BELOW THE HORIZONTAL				
	Co^{60}	Cs^{137}	X-RAY ENERGY (KEV EFF) 180	120	70	Co^{60}	Cs^{137}	X-RAY ENERGY (KEV EFF) 180	120	70	Co^{60}	Cs^{137}	X-RAY ENERGY (KEV EFF) 180	120	70
0	0.93	0.98	0.84	0.83	0.79	1.00	1.08	0.99	0.99	1.10	0.97	1.01	0.95	0.95	0.95
	0.97	1.01	1.06	1.21	1.20	1.00	1.08	1.21	1.35	1.28	0.95	1.03	1.05	1.13	1.05
45	0.85	0.91	0.79	0.78	0.60	0.93	0.96	0.84	0.85	0.68	0.88	0.86	0.78	0.82	0.60
	0.90	0.90	0.89	0.96	0.76	0.94	1.00	1.02	1.10	0.84	0.90	0.93	0.91	1.00	0.70
90	0.62	0.55	0.89	0.90	0.69	0.68	0.67	0.69	0.72	0.42	0.90	0.98	0.88	0.94	0.73
	0.42	0.39	0.28	0.25	~0	0.82	0.74	0.81	0.84	0.34	0.96	1.04	0.90	0.93	0.75
135	0.82	0.89	0.76	0.74	0.53	0.89	0.96	0.78	0.75	0.55	0.88	0.99	0.75	0.79	0.69
	0.37	0.29	0.23	0.20	~0	0.30	0.29	0.22	0.20	~0	0.40	0.32	0.22	0.19	0.06
180	0.93	1.00	0.99	1.05	1.02	0.95	1.04	0.88	1.00	1.05	0.94	1.00	0.94	1.05	1.15
	0.59	0.50	0.41	0.37	0.24	0.51	0.44	0.35	0.32	0.15	0.28	0.19	0.15	0.14	0.05
225	0.88	0.93	0.84	0.80	0.69	0.93	0.97	0.75	0.72	0.55	0.94	0.88	0.91	0.99	1.10
	0.53	0.43	0.29	0.26	0.15	0.37	0.29	0.23	0.22	0.11	0.57	0.47	0.30	0.28	0.18
270	0.96	0.86	0.79	0.75	0.63	0.88	0.89	0.81	0.76	0.91	0.65	1.01	0.88	0.88	0.86
	0.70	0.72	0.59	0.56	0.44	0.91	0.94	0.94	0.93	1.03	1.02	1.06	0.90	0.89	0.82
315	0.92	0.84	0.76	0.72	0.66	0.96	1.01	0.86	0.78	0.78	0.92	0.95	0.80	0.77	0.73
	0.96	1.04	1.03	1.16	1.15	0.95	1.00	1.01	1.05	0.91	0.95	0.99	0.97	1.02	0.82

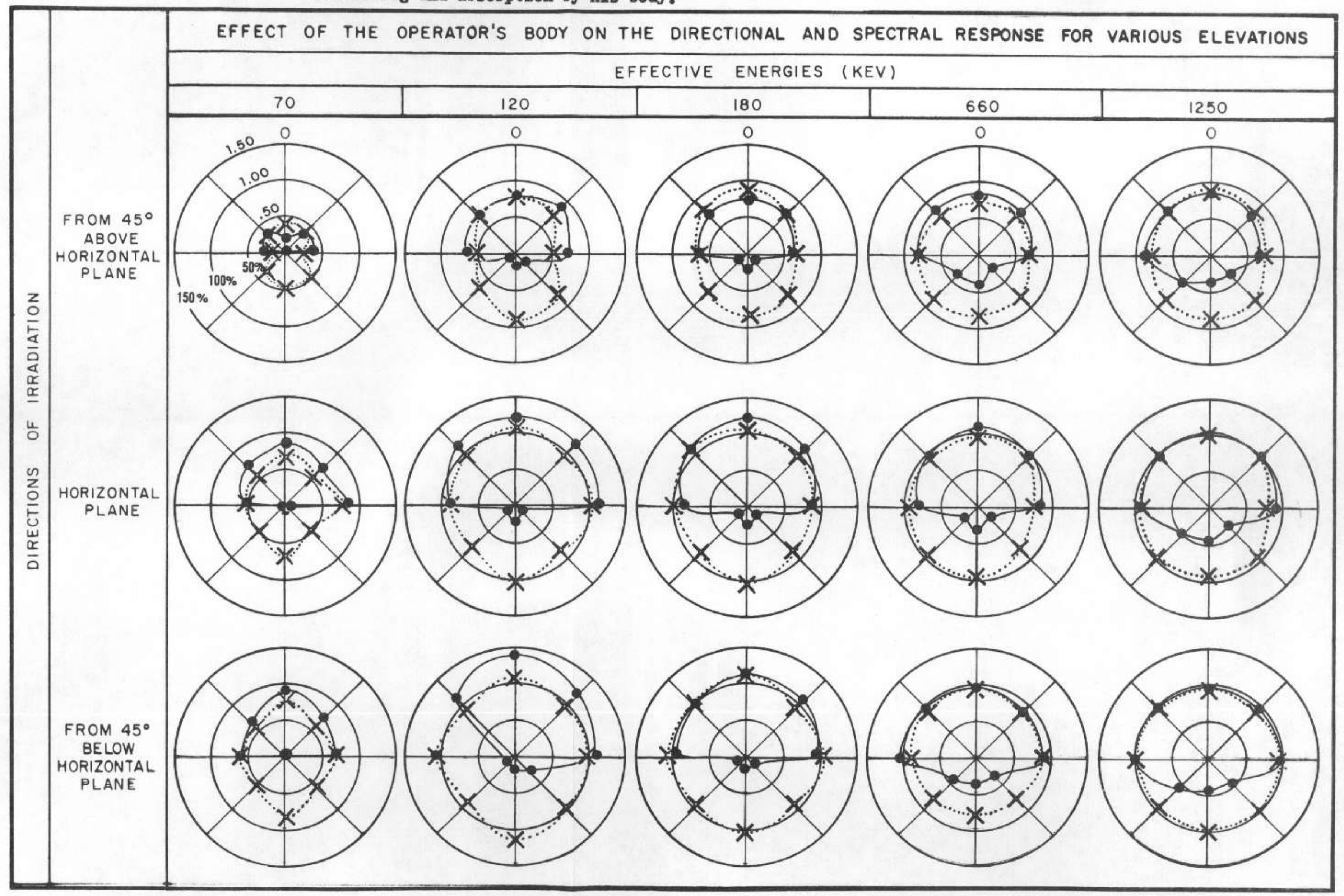
INTEGRATED RESPONSE TO VARIOUS DIRECTIONS AND ENERGIES OF IRRADIATION					
DIRECTION	Co^{60}	Cs^{137}	X-RAY ENERGY (KEV EFF) 180	120	70
HORIZONTAL PLANE	0.90	0.95	0.83	0.72	0.76
	0.73	0.72	0.72	0.75	0.58
45° BELOW HORIZONTAL	0.88	0.96	0.86	0.90	0.85
	0.75	0.75	0.68	0.70	0.55
45° ABOVE HORIZONTAL	0.86	0.87	0.83	0.82	0.70
	0.68	0.66	0.60	0.62	0.49

* See Section 4.1.4

AVERAGE RESPONSE FOR RADIATION FROM VARIOUS ELEVATIONS

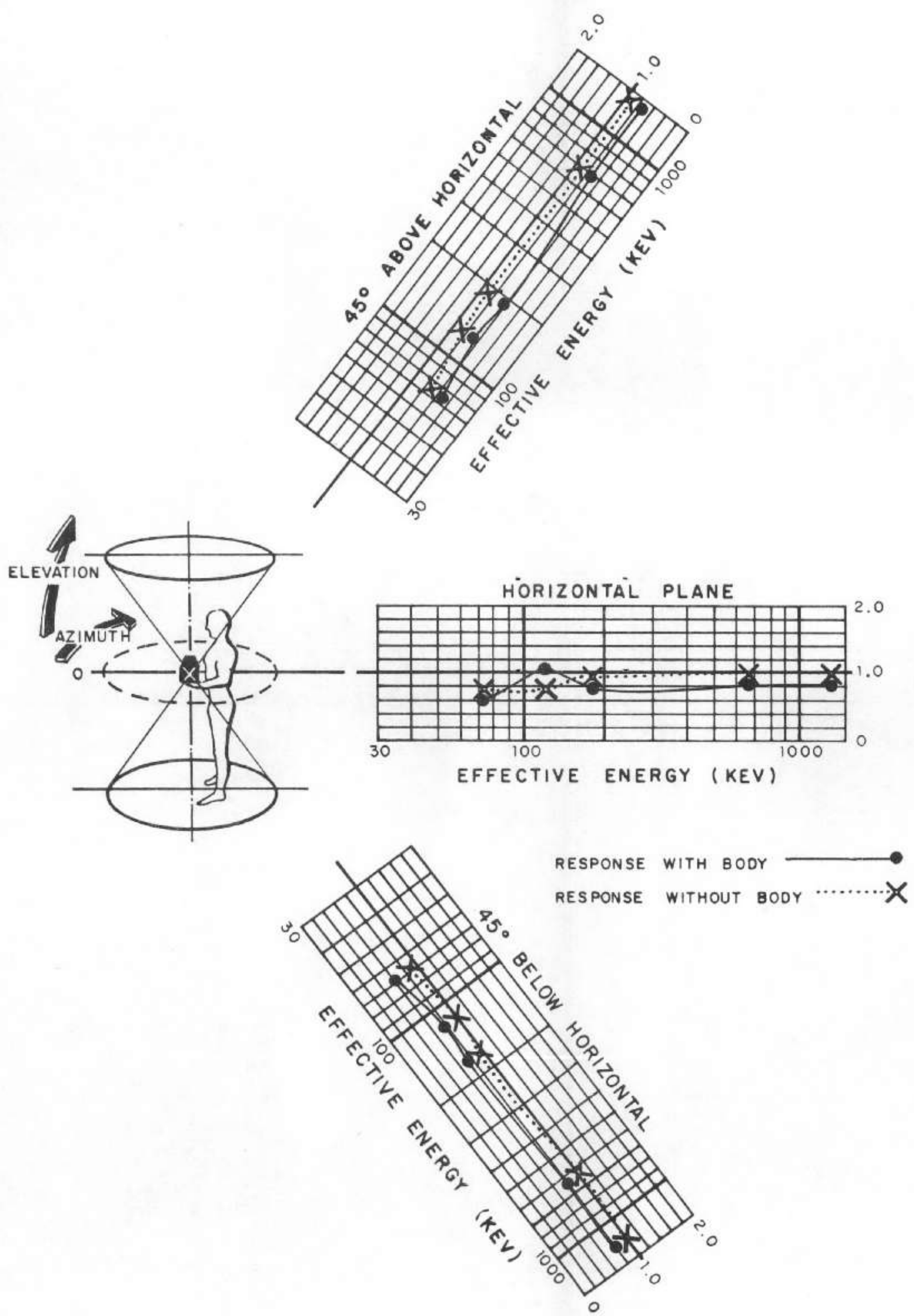


EFFECT OF THE OPERATOR: The curves given below show the response of the radiac to a variety of radiation energies and directions with and without the operator. The effect of the operator is due to radiation scattering and absorption by his body.



VALUES GIVEN ARE RELATIVE TO RESPONSE OF RADIAC ALONE TO Co^{60} RADIATION IN DIRECTION OF ZERO AZIMUTH AND ZERO ELEVATION.

AVERAGE RESPONSE FOR RADIATION FROM VARIOUS ELEVATIONS



PDR-63

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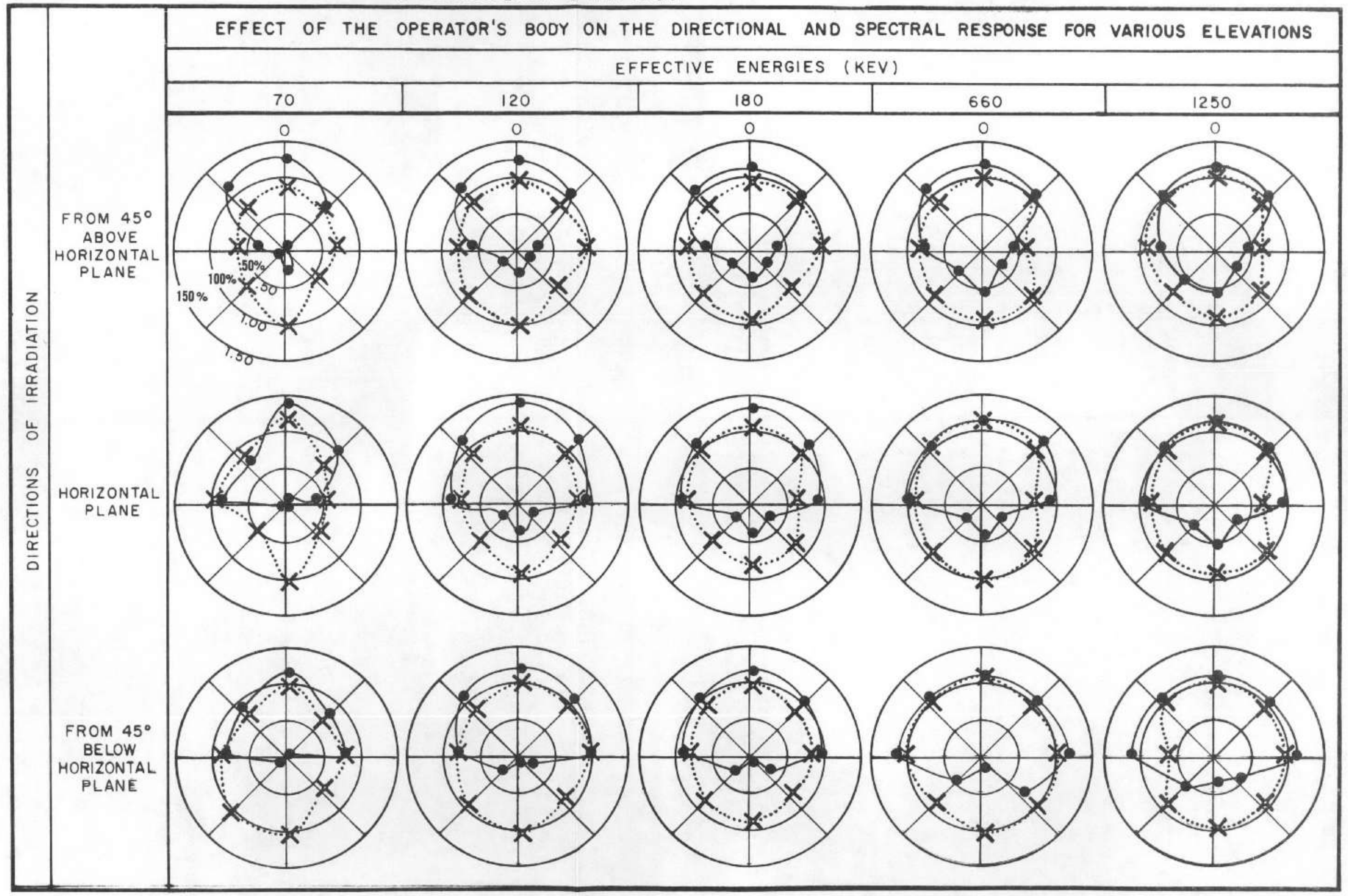
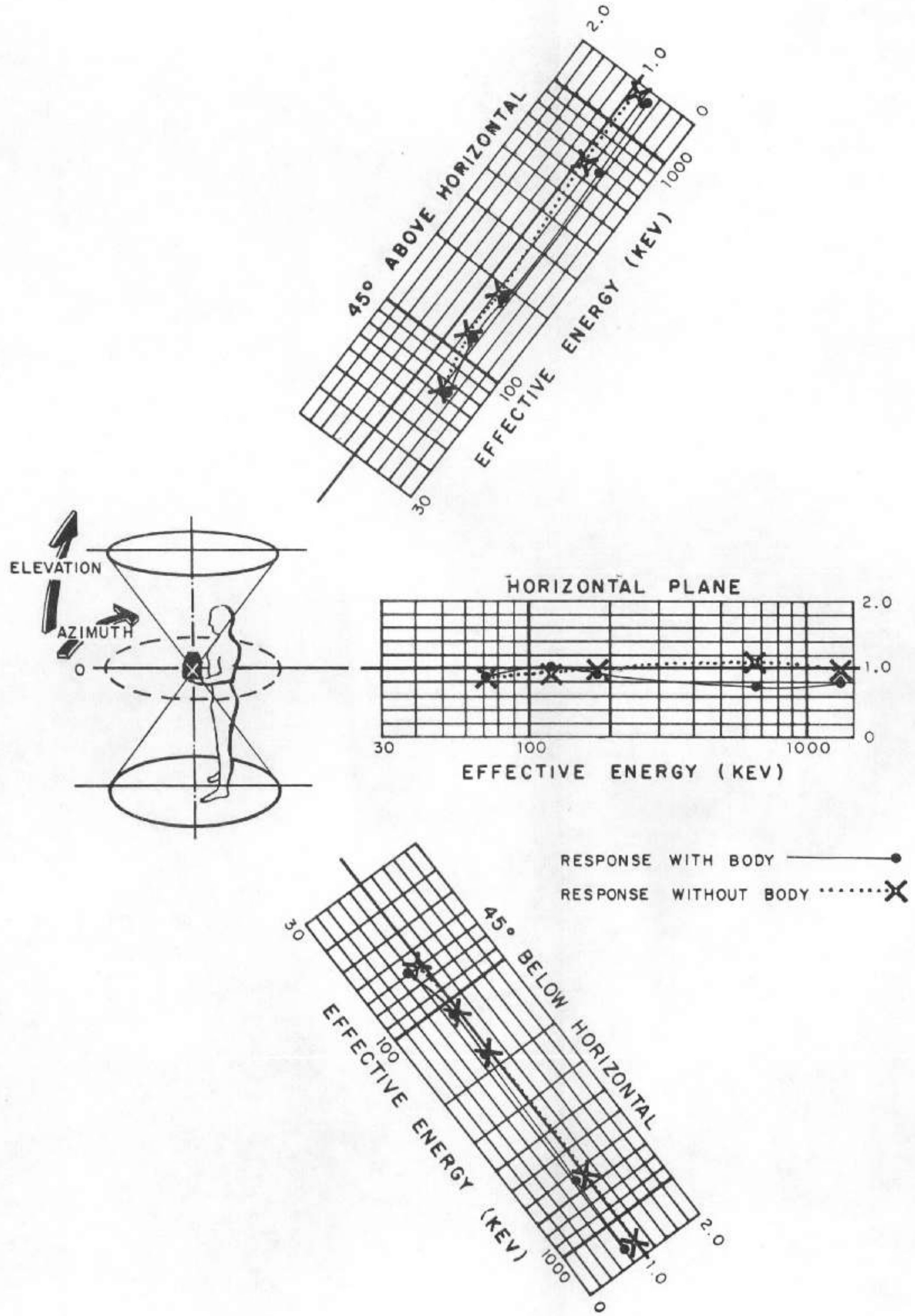
EFFECT OF THE OPERATOR: **The curves given below show the response of the radiac to a variety of radiation energies and directions with and without the operator. The effect of the operator is due to radiation scattering and absorption by his body.**

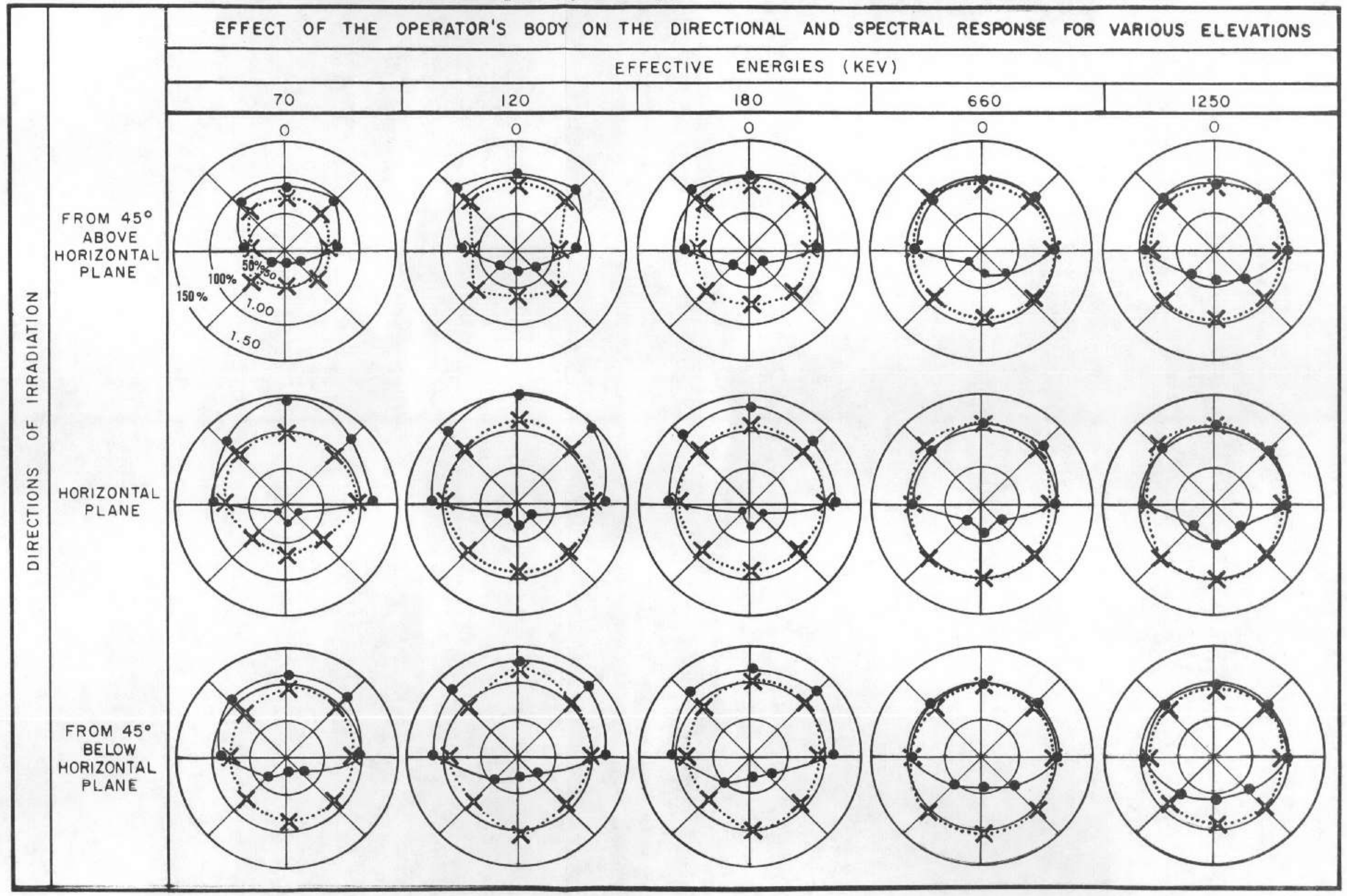


VALUES GIVEN ARE RELATIVE TO RESPONSE OF RADIAC ALONE TO Co^{60} RADIATION IN DIRECTION OF ZERO AZIMUTH AND ZERO ELEVATION.

AVERAGE RESPONSE FOR RADIATION FROM VARIOUS ELEVATIONS

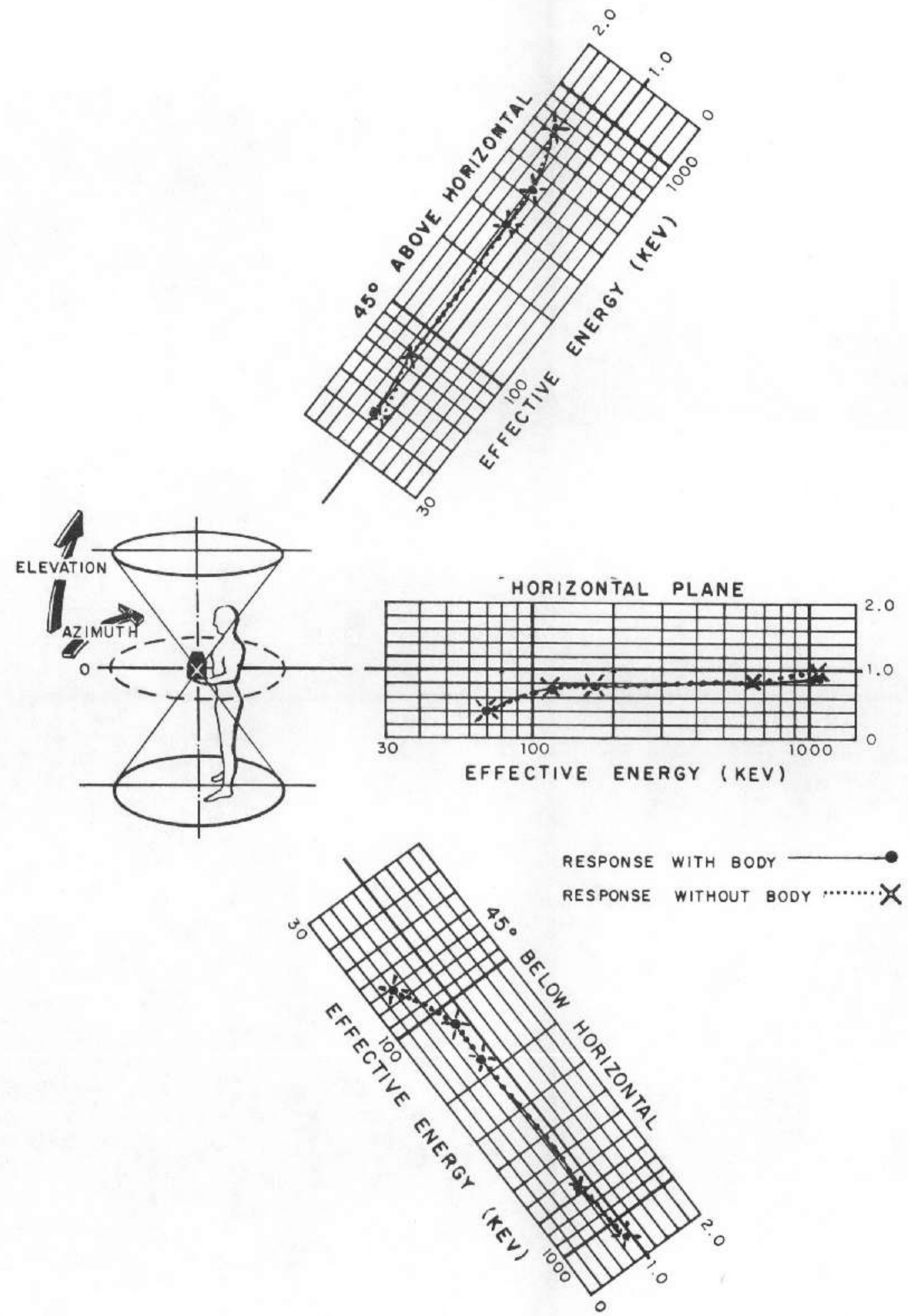


EFFECT OF THE OPERATOR: The curves given below show the response of the radiac to a variety of radiation energies and directions with and without the operator. The effect of the operator is due to radiation scattering and absorption by his body.

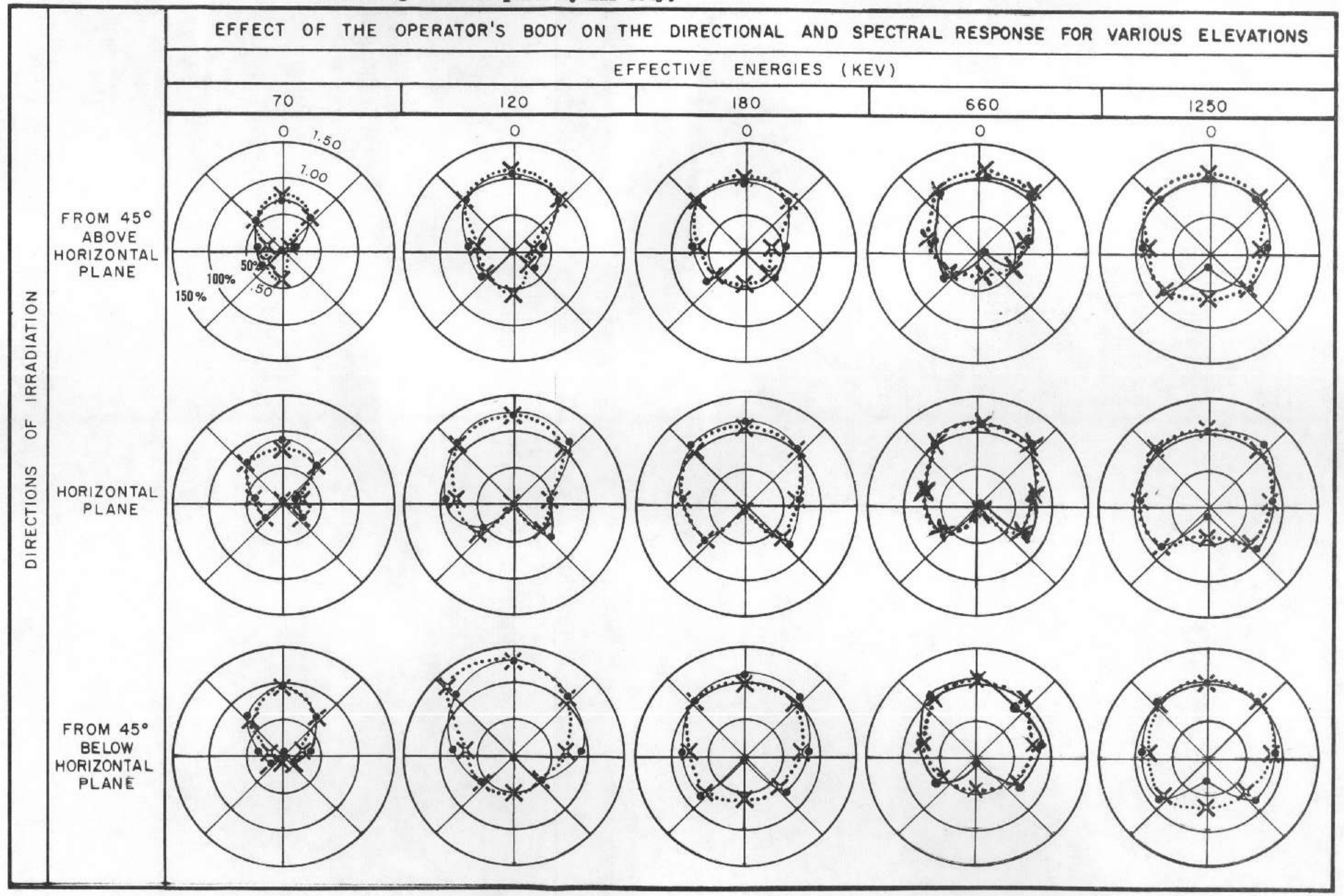


VALUES GIVEN ARE RELATIVE TO RESPONSE OF RADIAC ALONE TO Co^{60} RADIATION IN DIRECTION OF ZERO AZIMUTH AND ZERO ELEVATION.

AVERAGE RESPONSE FOR RADIATION FROM VARIOUS ELEVATIONS



EFFECT OF THE OPERATOR: **The curves given below show the response of the radiac to a variety of radiation energies and directions with and without the operator. The effect of the operator is due to radiation scattering and absorption by his body.**



VALUES GIVEN ARE RELATIVE TO RESPONSE OF RADIAC ALONE TO Co^{60} RADIATION IN DIRECTION OF ZERO AZIMUTH AND ZERO ELEVATION.

TABLE 6

Response of DT-60(XN-2)/PD Dosimeters
to Radiation With/Without Phantom

Dosimeter No.	Total Exposure (r)	Indicated Exposure (r)	Phantom
1	12.4	12.0	Without
2	12.4	13.0	Without
3	15.8	11.0	With
4	15.8	10.0	With

Note: The percentage total exposure for each exposure dose was as follows: (1) for 35, 70, 120, and 180 keV (eff) X rays; 13, 11, 15, and 22, respectively; and (2) for Cs^{137} and Co^{60}, 26 and 11, respectively. These percentages were chosen arbitrarily because of exposure time considerations.

4.1 General Discussion of Results

The qualitative aspects of the point source measurements are about as one would expect: the body of the operator attenuates radiation directed through it, and the radiac response is affected significantly. For low energies the response is often completely suppressed. The fact that some radiation would be scattered into the detector was anticipated; however, the effect on the response of a radiac is not readily computed and, unlike narrow beam attenuation, there was no ready means of estimating the magnitude that could be expected. The results show that there is a substantial rise in detector response when the operator is facing the source and is near the radiac. This rise in response can only be ascribed to radiation scattering by the operator into the detector. He becomes, in effect, a secondary radiation source.

All radiacmeters have dense parts that shield the detector in certain directions of irradiation. If the radiac positions used in this investigation had been changed, the results could have been quite different. As explained in paragraph 3.3, these positions were chosen because they are the positions likely to be used unless other usage doctrines are established.

The operator is a source of scattered radiation and is an attenuator of the direct radiation. His effect on the response of a

radiacmeter will be large unless the radiacmeter already has reduced sensitivity in the appropriate directions. The effects of attenuation and scatter are opposite in sense; thus they tend to compensate when they occur together, and the net change is reduced. It is apparent, however, that the accuracy of any radiac depends upon the gamma field configuration and upon the way the radiac is used in it.

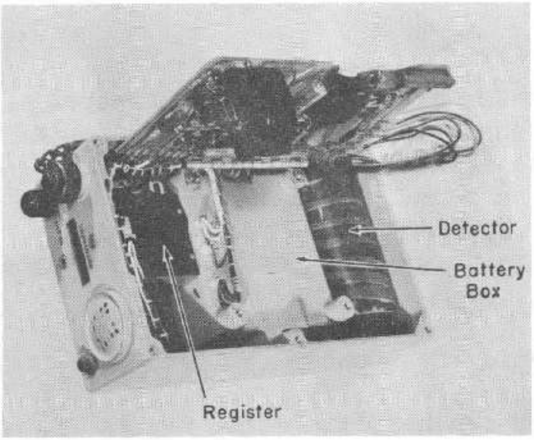
4.1.1 IM-108A/PD, IM-153/PD and PDR-63

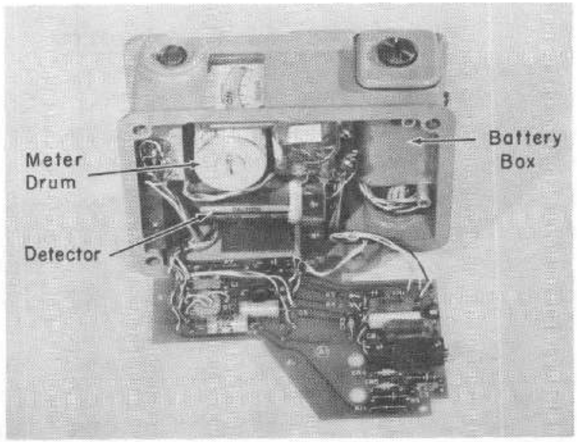
For the test positions used with the IM-108A/PD, PDR-63, and IM-153/PD, the sides that are open in Figs. 9a, b, c were next to the phantom. The direction of direct radiation into the radiacmeters for 0 deg, 45 deg, and 315 deg azimuth was into the side opposite the opened side. (Note: the radiac cases were not open during test.) Radiation at these angles back-scattered from the phantom was, then, directed into the side shown opened. The detectors of these three radiacmeters are not shielded by internal parts from radiation entering from the horizontal plane or below it. Tables 2 through 5 (0 deg azimuth; horizontal, and 45 deg below horizontal) show that each radiacmeter is relatively insensitive to these elevation changes of the direct radiation and that the scattered radiation is strongly effective in increasing response.

In the case of radiation from 45 deg above the horizontal, either direct or back-scattered, the response of each radiac is noticeably affected by parts layout. The dense parts of the PDR-63 are located at the ends of the case and toward the side away from the operator. (The cylindrical meter drum seen above the detector in Fig. 9b consists mainly of a thin aluminum shell.) The response changes very little when the direct radiation comes from 45 deg above the horizontal for 0 deg azimuth, but is reduced somewhat for 45 deg and 315 deg azimuth where dense parts partially obscure the detector (Table 5). Back-scatter from the phantom, however, is effective for all these directions because the same parts do not shield the detector from the side toward the operator. The dense parts of the IM-108A/PD and IM-153/PD are directly above the detector and are effective in shielding both direct and back-scattered radiation. Tables 3 and 4 show that the response to both back-scattered and direct radiation from 45 deg above the horizontal is depressed for 0 deg, 45 deg, and 315 deg azimuth.

4.1.2 IM-125/PDR-43

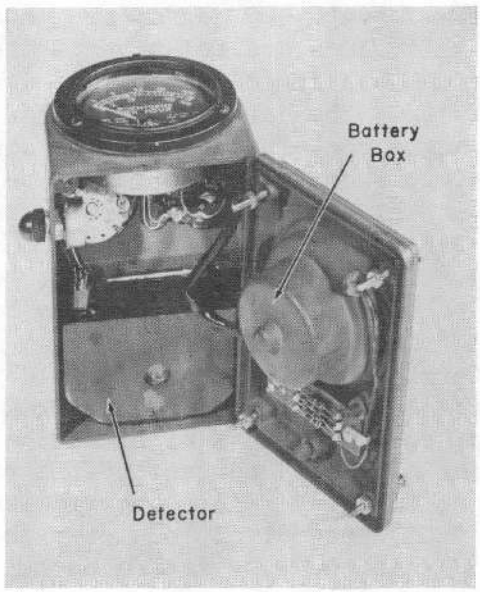
The IM-125/PDR-43 is relatively insensitive to back-scatter from the operator because the dense internal parts are grouped between the





(a) IM-153(XN-1)/PD

(b) PDR-63



(c) Radiacmeter IM-108/PD

Fig. 9 Internal Parts Arrangements of Radiacmeters IM-153(XN-1)/PD, PDR-63, and IM-108/PD

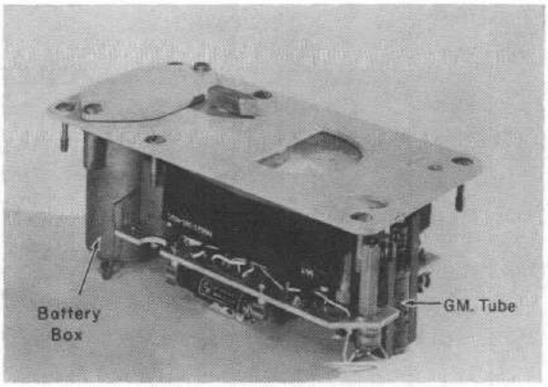
detector and the operator (Fig. 10).

4.1.3 DT-60(XN-2)/PD Dosimeters

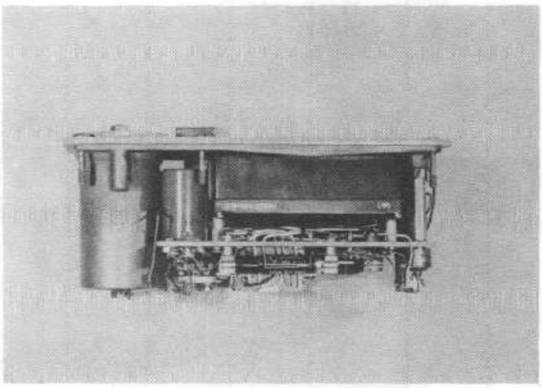
The results from the DT-60 dosimeter exposures should be especially noted. The means for controlling energy and directional response that have been built into them are quite effective for the dosimeters alone; but when they were attached to the phantom, a large error resulted. Further investigation of the DT-60(XN-2)/PD response with operator is indicated and, if the results warrant, a new filter arrangement should be designed.

4.1.4 Net Effect of the Operator on Radiac Response

The net effect of the operator on radiac performance when the radiac is carried, as indicated in paragraph 3.3, is to measurably reduce the response of the IM-108A/PD, IM-153/PD, and PDR-63. The response of the IM-125/PDR-43 to Co^{60} and Cs^{137} is reduced slightly and is the same for 180, 120, and 70 keV (eff). The extent of the reduction in responses is shown in Table 7. Tables 8 and 9 show the average responses of the radiacs to radiation 45 deg above, 0 deg (horizontal plane), and 45 deg below through 360 deg of arc in each plane with and without the phantom. All values are relative to the responses of the radiacs to Co^{60} in the calibrating direction, as described in paragraph 3.4. Note that, in Table 9, the data indicate that for the minimum 2.8π steradians solid angle contained within the boundaries of the exposure conditions, e.g., from 45° above to 45° below the horizontal and through 360° of azimuth, the responses of the radiacs are in the range 0.67 to 0.83 of the true free-field dose rates for Co^{60}, Cs^{137}, and 180, 120 keV (eff). The reduced responses at 70 keV (eff), though, are in line with the "roll-off" at lower energies recommended by Alpen[11] for deep dose measuring radiacs. (Note: While 4π steradian response cannot be directly determined from the data, field test results indicate that the flux incident on a phantom and radiac from the remaining 1.2π steradian solid angles, covering the zenith and the ground directly below, probably does not exceed 15 percent of the total dose in an extended fission product field.[12] Since the radiacs have appreciable response to radiation from these directions over the energy range of concern, it is believed that the 2.8π data closely approaches that which would be obtained from a 4π field.)



(a) Quarter-view showing GM Tube



(b) Side-view showing battery use on left, meter top, center-right

Fig. 10 Internal Parts Arrangement of Radiacmeter IM-125/PDR-43

TABLE 7

Reduction in Radiac Response (Percent) Caused by Phantom
Exposure Solid Angle of 2.8π Steradians

Radiac Type	Radiation Energy (MeV)				
	1.1, 1.3 (Co^{60})	0.667 (Cs^{137})	0.180 (eff)	0.120 (eff)	0.070 (eff)
IM-108A/PD	15	24	6	7	8
IM-153/PD	19	19	30	21	33
PDR-63	18	24	20	15	30
IM-125/PDR-43	4	4	0	0	0

TABLE 8

Radiac Response, No Phantom
Relative to Co^{60} in Calibrating Direction
Exposure Solid Angle of 2.8π Steradians

Radiac Type	Radiation Energy (MeV)				
	1.1, 1.3 (Co^{60})	0.667 (Cs^{137})	0.180 (eff)	0.120 (eff)	0.070 (eff)
IM-108A/PD	0.93	0.99	0.85	0.89	0.74
IM-153/PD	0.91	0.83	0.90	0.89	0.52
PDR-63	0.88	0.93	0.84	0.81	0.77
IM-125/PDR-43	0.86	0.75	0.75	0.73	0.39

TABLE 9

Radiac Response, with Phantom
Relative to Co^{60} in Calibrating Direction
Exposure Solid Angle of 2.8π Steradians

Radiac Type	Radiation Energy (MeV)				
	1.1, 1.3 (Co^{60})	0.667 (Cs^{137})	0.180 (eff)	0.120 (eff)	0.070 (eff)
IM-108A/PD	0.79	0.75	0.80	0.83	0.68
IM-153/PD	0.74	0.67	0.63	0.70	0.35
PDR-63	0.72	0.71	0.67	0.69	0.54
IM-125/PDR-43	0.83	0.72	0.75	0.73	0.39

5. SCATTER ANALYSIS MEASUREMENTS

The results of the initial series of measurements showed that the operator is an important secondary radiation source when he is near the radiac in a radiation field.

In the past, the energy-directional dependence of radiacs has been an important design consideration. It has also been recognized that attenuation by the operator causes large response changes and that scattering may be important. However, details of the characteristics of these effects have not been available for design and usage doctrine purposes.

Narrow beam attenuation by the operator presents no serious radiac design problem, in principle, since an appropriate set of attenuation data could be assembled to use in developing equipment and usage procedures. The effects of scattering from the operator on radiac performance, though, have been less well understood; therefore, a series of measurements was performed to provide further information about origins of the scattered radiation and the importance of operator-scatter relative to other scatter sources.

The measurements were made using the PDR-63 as a detector. The experimental conditions are given below:

a. Spectra used: 180, 120, and 70 keV (eff), as described in paragraph 3.4.9;

b. Irradiating direction: 0 deg azimuth with irradiation in horizontal plane;

c. Measurements were made with the phantom and repeated without the phantom.

d. Measurements were made with the broad irradiating beam used previously during this investigation.

e. Measurements were made with and without a 1/2-in. thick Pb mask (large Pb mask of Fig. 11) placed in front of the radiac to absorb radiation coming from regions between the radiac and the irradiating source.

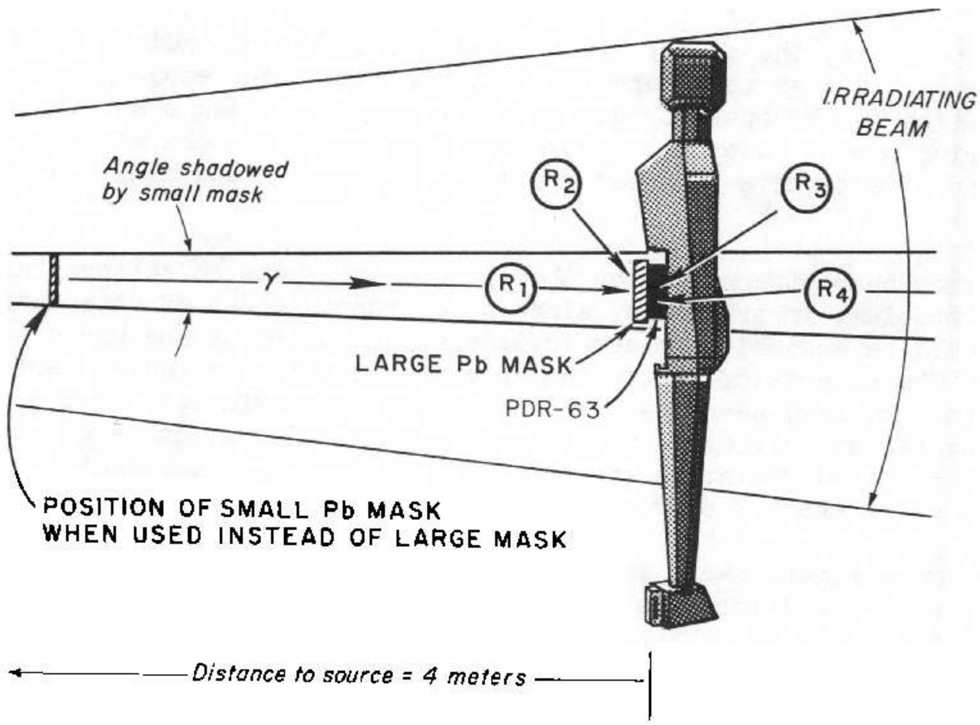


Fig. 11 Scatter Measurement Test Set-up

f. One series of measurements was made with a small cross-section area Pb mask substituted for the large mask. The small mask was placed about half way between the source and the radiac so that the radiac was just shielded from the direct source radiation.

g. The source-detector distance was 4 meters.

h. The cross-sectional areas of the beams were established visually by use of a large ZnS plaque placed directly behind the PDR-63 radiac.

The experimental arrangement is shown schematically in Fig. 11.

5.1 Analysis of Scatter Measurements

For purposes of analysis, the total response of the radiac to each irradiation was taken to be the sum of additive responses to radiation coming from four general regions (sources). The responses to these subsidiary sources of radiation are described below.

R_1 = response due to the primary beam: the radiation originating in the solid angle subtended by the radiac at the source. This includes some small angle scattering resulting in virtually the same gamma energy as the unscattered radiation.

R_2 = response due to radiation scattered forward from outside the solid angle subtended by the radiac at the source.

R_3 = response due to radiation scattered backward from the surroundings into the radiac, but not including scatter from the solid angle subtended by the radiac at the source.

R_4 = response due to radiation scattered backward from the solid angle subtended by the radiac at the source. (R_3 and R_4 are not substantially different in nature. The arbitrary separation in the analysis was for convenience in computing because the Pb mask interfered with the portion called R_4 whenever it was used.)

5.1.1 Zero Azimuth, Phantom Back-scatter

At zero azimuth the phantom is facing the radiation source. The

zero azimuth results are given in Table 10. All measurements with each spectrum are given relative to the results of measurement Number 1 made with that spectrum.

TABLE 10

Scatter Measurements Using Large Pb Mask

Measure-ment No.	Was Phantom Used?	Was Large Pb Mask on Radiac?	Relative Response for Each Effective Energy		
			180 keV	120 keV	70 keV
1	Yes	No	1.00	1.00	1.00
2	Yes	Yes	0.14	0.17	0.08
3	No	No	0.87	0.82	0.90
4	No	Yes	Negligible	Negligible	Negligible

The results of these measurements imply the following:

a. The Pb mask suppresses R_1 and R_2 for energies below 250 keV;

b. R_3 and R_4 are negligible for energies below 250 keV when the phantom is not present.

For each of the measurements shown in Table 10, different combinations of the subsidiary sources can be considered effective. For the measurements in zero azimuth, these combinations are as follows:

Measurement Number	Effective Sources	Comments
1	R_1, R_2, R_3, R_4	Broad beam, no Pb mask;
2	R_3	R_1, R_2, R_4, screened by large Pb mask, see (b) above;
3	R_1, R_2	See (b) above;
4	None	See (a) and (b) above.

These data also provide enough independent values of response to compute the contribution of back-scatter from the operator as well as that of the direct and forward-scattered radiation. For measurements in zero azimuth, these values are given in Table 11.

TABLE 11

Source Contribution with Large Pb Mask

Measurement Number	Source	Type	Relative Response for each Effective Energy 180	120	70
1	R1, R2, R3, R4	Direct, forward & back-scatter	1.00	1.00	1.00
2	R3	Back-scatter from phantom	0.14	0.17	0.08
3	R1 + R2	Direct and forward-scatter	0.87	0.82	0.90
4	None	Air back-scatter, solid angle subtended by radiac	--------Negligible--------		

The response to radiation sources R1 and R2 is the response that a radiac has to a radiation beam in the absence of an operator. R3 and R4 are sources of scattered radiation from the operator and are present whenever a radiac is being used. R4 was negligible, however, for these and subsequent measurements; therefore, it will not be referred to in the discussions that follow.

5.1.1.1 Relative Magnitudes of R_1 and R_2

The relative magnitudes of R_1 and R_2 could not be estimated separately because the large Pb mask shielded both components simultaneously. They were separated experimentally by using a smaller (2 x 2 x 1/2 in.) Pb shield positioned between the source and the radiac as shown in Fig. 11. The small Pb block was suspended by cords and maneuvered in the irradiating beam until the radiac was just obscured. The correct position was found by irradiating the radiac and observing its projection on a ZnS plaque placed behind it. By this means, R_1 could be effectively eliminated without decreasing R_2 substantially. The results of these measurements are given in Table 12.

TABLE 12

Scatter Measurements Using Small Pb Mask

Measurement Number	Was Phantom Used?	Was Small Pb Mask Used?	Relative Response for Each Effective Energy		
			180 keV	120 keV	70 keV
5	Yes	No	1.00	1.00	1.00
6	Yes	Yes	0.19	0.22	0.12
7	No	No	0.87	0.81	0.91
8	No	Yes	0.06	0.05	Negligible

The effective sources for each measurement were as follows:

Measurement Number	Effective Sources
5	R_1, R_2, R_3
6	R_2, R_3
7	R_1, R_2
8	R_2

The computed relative values of the response for each spectrum are given in Table 13.

TABLE 13

Values of Responses from Measurements with Small Pb Mask

Measurement Number & Effective Sources	Relative Response for Each Effective Energy		
	180 keV	120 keV	70 keV
5 = $R_1 + R_2 + R_3$	1.00	1.00	1.00
6 = $R_2 + R_3$	0.19	0.22	0.12
7 = $R_1 + R_2$	0.87	0.81	0.91
8 = R_2	0.06	0.05	Negligible
7 - 8 = R_1	0.81	0.76	0.91
6 - 8 = R_3	0.13	0.17	0.12

5.1.2 Equivalence of Phantom and Human Operators

It had been assumed that for the purposes of this investigation the phantom was a satisfactory substitute for a real operator (section 2 (a)). To substantiate this, comparison measurements were made substituting one of the authors for the phantom. This man weighed 150 lb and was 5'8" tall. Some of the previous measurements using the large Pb mask (180 keV) were repeated, as indicated in Table 14. Except for the real operator, they duplicated measurement Numbers 1, 2, and 3 shown in Table 11.

TABLE 14

Scatter Measurements Using a Real Operator

Measurement Number and Effective Sources	Relative Response for 180 keV Effective		
	Real Operator	Phantom	
		Small Mask*	Large Mask**
1 = $R_1 + R_2 + R_3$	1.00	1.00	1.00
2 = R_3	0.13	0.13	0.14
3 = $R_1 + R_2$	0.87	0.87	0.87

* Values from Table 12
**Values from Table 11

The close correlation between the effect of the phantom and the effect of a real operator establishes their equivalence satisfactorily with regard to radiation scattering.

6. CONCLUSIONS

1. The presence of an operator (phantom) can materially reduce the response of present military gamma radiation detecting radiacs in a free-field radiation environment when carried and used in the manner described in paragraph 3.3 of this report. The extent of the effect of the operator is dependent on the design of the radiac and the energies of the gamma photons in the immediate environment of the radiac. Reductions in radiac response to gamma radiation energies in the range of 70 to 1300 keV over the 2.8π steradian solid angle discussed in Section 4.1.4 are as follows:

(a) IM-108A/PD--down 15 to 25 percent for Co^{60} and Cs^{137}, and down 5 to 10 percent for 180 to 70 keV.

(b) IM-153/PD--down 20 percent for Co^{60} and Cs^{137}, and down from 20 percent to 30 percent for 180, 120, and 70 keV.

(c) PDR-63--down 20 to 25 percent for Co^{60} and Cs^{137}, down 15 to 30 percent for 180, 120, and 70 keV.

(d) IM-125/PDR-43--down 4 percent for Co^{60} and Cs^{137} and no loss at 180, 120, and 70 keV.

(e) DT-60(XN-2)/PD--down 30 to 35 percent. (See paragraph 3.4.4 for radiation energies and exposure conditions.)

The differences in decrease of response from radiac to radiac and the energy dependence of decrease can be explained as follows:

(f) IM-108A--the radiac is held close to the operator's body so that his body subtends a solid angle approaching 2π steradians. Therefore, all energies of direct radiation passing through his body are attenuated. Conversely, the relatively thin walls of the radiac case and ion chamber, combined with ion chamber placement, permit the radiac to respond to low energy back-scatter from direct radiation. Since the

population of back-scattered low energy photons increases with decreasing direct radiation energies, back-scatter response compensates differentially for the various radiation energies.

(g) IM-153/PD and PDR-63--the lack of compensation at low energies is due to thicker instrument case walls and to detector volume placement in the radiacs.

(h) IM-125/PDR-43--the detector is located sufficiently far (8 in.) from the operator that the solid angle subtended by him is appreciably smaller than with the other radiacs; therefore, direct body attenuation is lowered so that response to back-scatter is compensatory for lower energies and nearly so for Co^{60} and Cs^{137}.

(i) DT-60(XN-2)/PD--problems in reading small DT-60 radiation doses preclude any attempt to analyze decrease in response as a function of gamma energy. Certainly, though, any compensatory response to back-scatter would be least for these devices because (1) the operator's body would attenuate direct radiation over a 2π steradian solid angle, minimum; and (2) the effective source of back-scattered radiation would be small indeed.

The net effect of the presence of the operator on radiac response in a free-field radiation environment is (1) to attenuate radiation which must pass through him to interact with the detector of the radiac, and (2) to be a secondary source of lower energy back-scattered photons produced by interaction of direct radiation with the operator's body.

APPENDIX

RADIACMETER DESCRIPTIONS

A general reference for each radiacmeter is given below. Descriptive material from these publications is reproduced in the following pages.

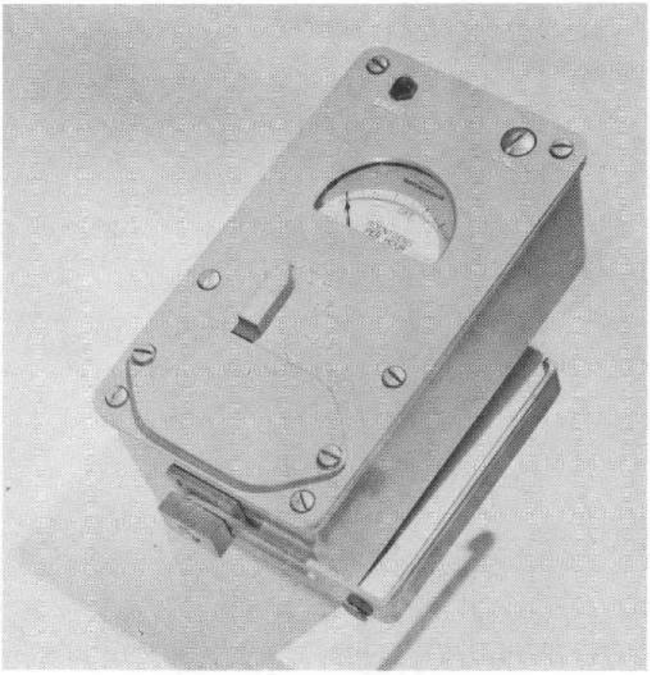
IM-125/PDR-43: "Technical Manual for Radiac Set AN/PDR-43," NAVSHIPS 93225(A).

IM-153(XN-1)/PD: "Technical Manual for Radiac Alarm Dosimeter IM-153(XN-1)/PD," NAVSHIPS 93510.

IM-108/PD: "Operation and Organizational Maintenance, Radiacmeter IM-108/PD," TM 11-6665-200-12; Hdqtrs, Dept. of the Army, Nov 1958.

PDR-63: "The RGI-20 Radiac System--A Wide-Range Beta-Gamma Instrument," (Note: The RGI-20 has recently been designated the PDR-63. The complete radiac set number has not been assigned.), K. Miller and G. T. Kiyoi, USNRDL-TR-523, Sep 1961.

DT-60(XN-2)/PD: "Directory of Radiac Equipment," NAVSHIPS 94200.5.



INTENDED USE: Gamma-beta field survey and fleet operations.

TYPE OF RADIATION DETECTION CAPABILITY: Gamma + beta and gamma only.

TYPE OF DETECTOR EMPLOYED: Geiger-Mueller tube.

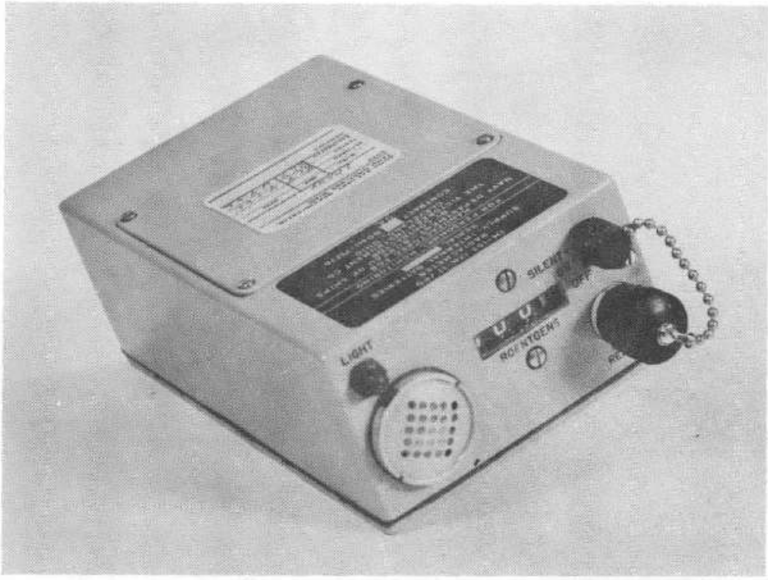
INSTRUMENT OPERATIONAL RANGE: 0-5, 0-50, and 0-500 r/hr for gamma detection. An indication of the presence of beta may be obtained on all three ranges.

INSTRUMENT POWER: Two 1-1/2 volt BA-30 batteries or ordinary flashlight cells.

CARRYING MODE: Hand carried or slung from the shoulder by plastic belt.

INSTRUMENT READOUT: An internally illuminated scale changing meter calibrated in roentgens per hour displays information received by the detector.

IM-153/PD



INTENDED USE: The radiac alarm dosimeter was designed for the use of personnel entering a radiologically contaminated area. Dose and doserate information for immediate hazard evaluation can be obtained from this instrument.

TYPE OF RADIATION DETECTION CAPABILITY: Gamma.

TYPE OF DETECTOR EMPLOYED: Recycling ion chamber.

INSTRUMENT OPERATIONAL RANGE: The instrument is capable of integrating and displaying up to 999.9 roentgens.

INSTRUMENT POWER: Power for the instrument is supplied by two 1-1/2 volt Ba-30 batteries or ordinary flashlight cells.

CARRYING MODE: The radiacmeter is designed to be hand carried or to clip on the operator's belt.

INSTRUMENT READOUT: The instrument uses a totalizing register and an alarm sounder. The instrument is capable of integrating the radiation detected in roentgens in steps of 0.1 for doserates from 0.1 r/hr to beyond 500 r/hr. The device indicates dose and doserate by giving an audible "beep" for each recorded 100 milliroentegen plus a continuous alarm, activated when the counter indicates 1.0, 10.0 or 11.0, etc.

WEIGHT: The instrument weighs 3 lb with batteries.

PHYSICAL DIMENSIONS: 7 in. long x 4 in. wide x 2-1/4 in. deep.

IM-108/PD

INTENDED USE: Used for gamma field survey.

TYPE OF RADIATION DETECTION CAPABILITY: Gamma.

TYPE OF DETECTOR EMPLOYED: Ion chamber.

INSTRUMENT OPERATIONAL RANGE: 0-500 r/hr.

INSTRUMENT POWER: Three batteries; one 1.35 volt mercury BA-1288/U or Mallory Co. RM4R and two 5.2 volt mercury BA-1318/U.

CARRYING MODE: Carried either by a shoulder strap or clipped to the operator's belt.

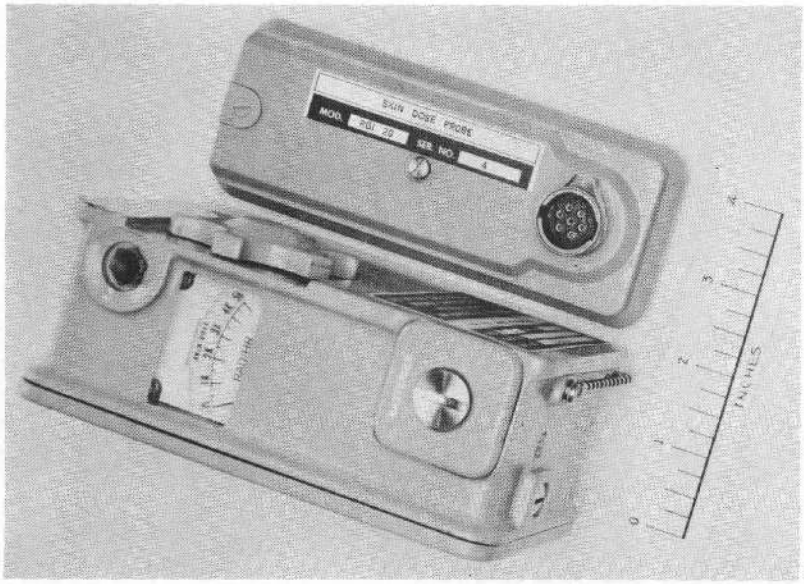
INSTRUMENT READOUT: A 3-1/2 in. meter calibrated in roentgens per hour: compressed, nonlinear scale, displays information received by the detector.

WEIGHT: 3 lb.

PHYSICAL DIMENSIONS: 6 x 4 x 4-1/2 in.

Note: The IM-108A/PD used in this investigation is a later model of the IM-108/PD. The IM-108A/PD has been modified by the Army Signal Depot and is now designated IM-174/PD. The radiacs are essentially the same insofar as response to radiation is concerned.

PDR-63



<u>INTENDED USE</u>: Multipurpose radiac for gamma beta field survey.

<u>TYPE OF RADIATION DETECTION CAPABILITY</u>: Gamma-beta.

<u>TYPE OF DETECTOR EMPLOYED</u>: Recycling ion chamber and plug-in skin dose probe.

<u>INSTRUMENT OPERATIONAL RANGE</u>: Ten linear scales; 0-1, 0-10, 0-100, 0-1000 mrad/hr; 0-2, 0-10, 0-100, 0-1000 rad/hr; and 0-500, 0-5000 rad/hr skin-dose.

<u>INSTRUMENT POWER</u>: Four size AA 1-1/2 volt batteries: rechargeable, "penlight cells" or BA-58.

<u>CARRYING MODE</u>: Belt carried by clip or slung from the shoulder by a plastic sling.

<u>INSTRUMENT READOUT</u>: Scale changing meter calibrated in rad per hour, and millirad per hour displays information received by the detectors.

<u>WEIGHT</u>: 2-1/2 lb.

<u>PHYSICAL DIMENSIONS</u>: 2-1/4 x 4 x 5-1/2 in.; probe dimensions are 5-1/2 x 2-1/4 x 1/2 in.

DT-60(XN-2)/PD

INTENDED USE: Detect accumulated radiation dose, personnel.

TYPE OF RADIATION DETECTION CAPABILITY: X rays and gamma rays.

TYPE OF DETECTOR EMPLOYED: Radio-photoluminescent silver activated glass.

INSTRUMENT OPERATIONAL RANGE: 0-600 r/hr.

CARRYING MODE: Suspended from neck of wearer by a chain or cord.

INSTRUMENT READOUT: When the DT-60(XN-2)/PD is placed in a CP95/PD or CP95A/PD Radiac Computer Indicator it is exposed to a source of ultraviolet light. The ultraviolet light causes the silver activated glass to emit an orange luminescence, the intensity of which is proportional to the total amount of radiation the glass has received. The information from the detector is displayed on a meter calibrated in roentgens per hour.

WEIGHT: 1 ounce.

PHYSICAL DIMENSIONS: A round plastic case 1-1/2 in. in diameter and 1/2 in. thick.

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DISTRIBUTION DATE: 5 March 1964

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